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ERGONOMICS

HUMAN FACTORS IN WORK, MACHINE CONTROL AND EQUIPMENT DESIGN

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ERGONOMICS

Human Factors in Work, Machine Control and Equipment Design

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THE STRENGTH OF THE LIFTING ACTION IN MAN

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The maximum isometric force exertable on a horizontal bar situated in a frontal plane was found to vary, for eight young male subjects and for the different lifting conditions observed, from 15 to 120 kg. Increase of foot placement distance from 30 cm to 50 cm effected the largest reduction in lifting force. The reduction produced by increase of grasp height from 12½ cm to 50 cm was very much less, and the effect of type of grasp (overhand or underhand) and type of lifting action (using or not using knee extension) was generally small. It appeared that the magnitude of the lifting force was largely determined by the magnitude of the force moment which the body mass could exert to counterbalance the reaction of the lifting force upon the body. The nature of the muscular activity associated with this stabilization of the body during lifting operations is discussed.

§ 1. Introduction

The ability of Man to lift and handle heavy loads distinguishes him strongly from other vertebrates. This ability has undoubtedly played—and continues to play—an important part in Man's social evolution, and it would be surprising if development of the ability, during human evolution, has not been responsible for some of the specific anatomical and physiological features of Man.

In spite of the practical and theoretical interest of the subject of human weight lifting, and in spite of the sporadic attention which the subject has received over a long period of time—De La Hire (1699) compared the strength of men and horses in lifting weights—no serious attempt appears to have been made to determine the maximum capacity of Man in normal weight-lifting operations. Data have been given for performance in championship weight lifting (Taygren 1950, Keeney 1955, Lietzke 1956), but such data refer to the trained performance of a small number of special lifting tasks which cannot be considered representative of normal, practical lifting operations. The application of ergometric methods to the study of voluntary muscular actions likely to be concerned in the lifting operation, in particular, the application of such methods to determine the strength of back and leg extension (Sargent 1897, Reijs 1921, Bedford and Warner 1937, Carpenter 1938, Tuttle *et al.* 1955) has yielded results which are not readily applicable to practical lifting actions until the manner in which these muscle groups participate in the lifting action is defined. Also, the conditions obtaining during the ergometric measurements were often somewhat artificial, and sometimes rather inadequately described.

Other investigations of the lifting action have not been concerned with the maximum performance. The metabolic energy expenditure for weight lifting operations has received some attention (Takenaka and Hatakeymaya 1939, Starr *et al.* 1945, Das 1951). The limited use that has been made of the EMG technique for the investigation of weight lifting has been reviewed recently by Floyd and Silver (1955), but here again the experimental conditions often appear to be somewhat artificial, and the relevance of the results to the operation of lifting heavy weights is not as a rule apparent.

An important aspect of the subject of weight-lifting operations is the risk of structural injury—in particular to the musculo-skeletal structure of the back—which appears to attend such operations. The literature on this aspect is quite extensive, but only brief reference seems desirable in this paper since the experimental approach to the causes of back injury during weight lifting is conspicuously absent. That lifting and handling operations have considerable attendant risks is attested by the statistical survey in the *Annual Reports of the Chief Inspector of Factories* (1954). For example, in the year 1953, 27·5 per cent of all accidents in factories occurred during the manual handling of goods. More specific statistical enquiries have established the high incidence of back injuries in tasks involving weight lifting (Wayne 1954, Russek 1955).

This widespread occurrence of injury, particularly to the lower back, has given rise to specific advice on allegedly safe methods of weight lifting (*Ministry of Labour and National Service* 1944, Anderson 1951, Cyriax 1954, Herford 1954, Wayne 1954, Floyd and Silver 1955). A common feature of this advice is that lifting by bending over the trunk, with the knees kept straight (referred to as ‘ derrick action ’ in this paper), is dangerous compared with the method of lifting which involves flexed knees and an upright trunk (‘ knee action ’). Unfortunately, the scientific basis of this advice is not at all clear, though it is sometimes claimed (but not experimentally proved) that ‘ knee action ’ is more powerful than ‘ derrick action ’. Floyd and Silver (1955) point out that the knee action method minimizes strain to the posterior ligament of the spine. Das (1951) found that the relative metabolic efficiencies of the two methods of lifting varied with the magnitude of the weight lifted.

Further consideration of the injury aspect of weight-lifting operations would be out of place here, for the experiments to be described are not primarily concerned with this aspect, although they will be concerned with certain comparisons of derrick and knee action lifting. Until the mechanical details of normal lifting operations have been established it would seem unwise to be dogmatic as to the mechanism of structural injury during lifting. It seems reasonable to suggest, however, that a lifting action of the derrick type is the natural method of lifting, if only because some persuasion seems to be necessary to ensure the adoption of the knee action. It would also appear that the human body, in carrying out lifting operations, is capable of stressing its structure up to, or even beyond, safe limits.

In designing the experiments described below, a dominant consideration was that there was no known description of normal lifting operations, and no known enumeration of the variables which might affect the lifting force. Even photographic records of the sequence of movements in lifting are not common in the literature (Morehouse and Cooper 1950, reproduce some representative photographs). Types of lifting operation, together with the variables likely to be involved, are therefore described in some detail in Appendix I. Reference to Appendix I may be necessary to clarify the description which follows of the types of lifting operations considered in this paper.

§ 2. METHODS

The strength of the lifting action was measured under the following defined conditions (see Appendix I for details of nomenclature) :

(i) The subject was instructed to exert a steady, maximum lifting force on a horizontal bar placed in a frontal (coronal) plane. The duration of the steady force was 3 seconds.

(ii) The bar was of circular cross section, 3·2 cm diameter and the span of the two-handed symmetrical grasp was maintained at 40 cm throughout.

(iii) Subjects were instructed to employ a closed grasp throughout, and both overhand and underhand grasps were investigated.

(iv) Three levels of grasp height were investigated, viz. 12·5, 25·0 and 50·0 cm above ground level.

(v) Foot stance was maintained at 20 cm throughout. No instructions were given, and no control was exercised during the experiments, on the degree of spread of the axes of the feet, or on the maintenance of ground contact at the heels during lifting operations.

(vi) Foot placement was investigated at three distances of heel contours from the frontal plane (including the axis of the horizontal bar), viz. 30, 40 and 50 cm.

(vii) In each lifting effort the subject was instructed to adopt one of two types of lifting action—either derrick action or knee action.

Apart from the specified conditions and controls indicated under the above headings, the subjects were free to employ any manoeuvres they wished to ensure that they exerted the maximum possible vertical lifting force.

2.1. *Recording of the Forces Exerted at Bar and at Feet*

The general arrangements for the experimental lifting operations are illustrated in Fig. 1. The subject stands on the surface of the force analysis platform with the posterior limits of the two foot axes coincident with the intersections of the stance lines and the specified foot placement line. The posterior limit of each foot axis (for the feet shod in plimsolls) was visually estimated from the heel of the footwear, and the foot placement was therefore subject to some experimental error, but it is unlikely that the placement error exceeded 0·5 cm in any direction in the horizontal plane. The horizontal bar, on which the lifting force was to be exerted, was adjusted to the selected grasp height. The subject was instructed to grasp the bar with both hands, with a closed grasp, overhand or underhand, and with the third digit of each hand aligned with its respective span mark on the bar. A lifting effort was then made with derrick or knee lifting action.

The recorded output of the force analysis platform resolved the force exerted by the feet on the surface of the platform. A separate photographic trace was obtained for the component normal to the platform surface and for the horizontal component in the sagittal plane of the subject. A simultaneous record was obtained of the vertical and horizontal sagittal components of the lifting force exerted on the grasping bar by the hands (see Fig. 2 ; Fig. 4 shows representative records). Horizontal components of the forces at the bar and at the platform surface in the frontal plane were not recorded, because preliminary experiments showed, as would be expected, that these components were quite negligible.

The manner by which the exterior forces exerted by the subject during lifting actions are resolved into their components along known axes, and recorded photographically, depends on the mechanical and electrical systems incorporated in the force analysis platform and transducer bar to which the horizontal grasping bar is attached (see Fig. 1). The details of the mechanical and electrical arrangements are somewhat complex, particularly in the case of the force analysis platform, and only brief descriptions will be attempted here. Essentially, the resolution of the forces is carried out by purely mechanical systems. The resolved components of force cause deflections of spring steel bars, the deflections being proportional to the force components. The deflections (and therefore the force components) are transduced to electrical changes by means of electric resistance strain gauges mounted on the spring steel bars, the strain gauges constituting the arms of Wheatstone bridge circuits. There is an independent bridge circuit for each force component, and the electrical outputs of the separate bridge circuits are simultaneously recorded photographically by a multi-channel galvanometer.

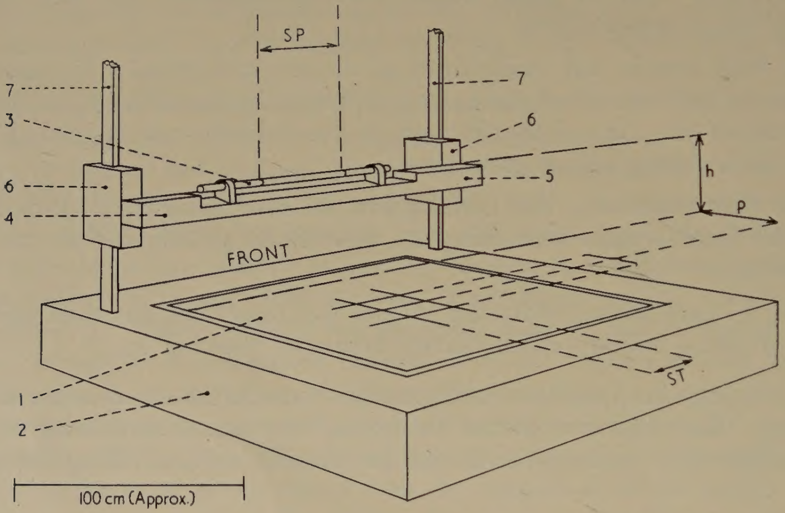

Figure 1. Diagrammatic rear left-hand perspective of the force analysis platform and grasp transducer bar. During lifting operations the subject faces the platform edge labelled ‘ Front ’. Description of other labelled items :—

1. Suspended surface of platform, marked with stance and foot placement lines.
2. Housing for suspension and transducer system of platform.
3. Grasping bar, with span lines marked.
4 & 5. Left- and right-hand grasp transducer systems. (For detail see Fig. 3.)
6. Vertically sliding boxes, carrying grasp transducer bar.
7. Vertical rails for sliding boxes.

h : Grasp height, in cm from platform surface.
p : Foot placement distance, in cm from vertical plane including the axis of the grasping bar.
SP : Grasp span (40 cm in investigation described).
ST : Foot stance (20 cm in investigation described).

The force analysis platform consists of a rigid metal platform, 120 cm square, on which the subject stands. The platform is suspended at each corner by a vertical length of piano wire, the other end of the wire being attached to the free end of a horizontally disposed spring steel bar. The roots of the four spring steel bars, one at each corner of the platform, are firmly clamped on a rigid steel chassis which is attached to the floor. Thus, a downward force normal to the surface of the platform, or the vertical component of a non-normal force, will cause a downward deflection of the four spring steel bars, the amount of deflection of each bar depending on the magnitude of the force and on the position, within the surface of the platform, at which the force is exerted. The bars are chosen to have identical deflection rates, so that the sum of the deflections of the four steel bars is proportional to the normal force exerted on the platform for all positions of the force within the platform surface. This summed deflection is transduced electrically by attaching paper mounted wire strain gauges near the roots of the steel bars, the corresponding gauges from the four steel bars being connected electrically in series to form one arm of a Wheatstone bridge. If the bridge circuit is initially balanced for no load on the platform, the subsequent resistance imbalance of the bridge, and the electrical output of the energized bridge, will be proportional to the force which is exerted normally to the platform surface. The output can be readily calibrated to give a record of FV (Fig. 2).

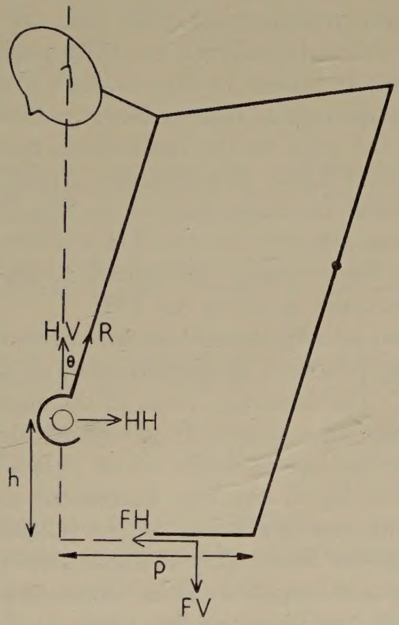

Figure 2. Diagrammatic left-lateral view, showing the disposition of body linkage during the performance of a derrick type lifting action at foot placement distance p and grasp height h, and the resolution of the external forces at the feet (FV and FH) and at the hands (HV and HH). The resultant (R) of HV and HH is shown acting through the axis of the arm link, at an angle θ with the frontal (coronal) plane of the subject.

A force, or a force component, exerted within the plane of the platform surface (that is, at right angles to FV), will tend to move the platform in the appropriate direction in the horizontal plane, and since there will be a negligible component of such a force along the four vertical suspension wires, no output will arise in the FV bridge.

Horizontal deflections of the platform parallel to FH (that is, parallel to the sagittal plane of the subject standing on the platform as indicated in Figs. 1 and 2) are resisted by two horizontal lengths of piano wire, which run immediately below and parallel to the right and left sides of the platform (see Fig. 1 for orientation). On each side the centre of the wire is firmly attached to the centre of the side of the suspended platform, and the front and rear ends of the wire are attached to the free upper ends of two vertical spring steel bars. The roots of the four vertical bars restraining movements of the platform along the front-to-rear (FH) axis are firmly clamped to the rigid steel under-chassis already referred to. The piano wires connecting the vertical steel bars are set in initial tension, so that a horizontal force exerted in either direction (front-to-rear or rear-to-front) causes a change in deflection of all four steel bars, the sum of the deflections being proportional to the magnitude of the horizontal force. The deflection sum is electrically transduced, to produce a porportional electrical output in the FH bridge circuit, in a similar manner to that already described for FV. The mechanical and electrical arrangements for recording horizontal forces along the left-to-right axis are essentially the same as those for FH.

Thus a force exerted in any downward direction on to any point of the surface of the suspended platform is analysed into its components along three known rectilinear axes. The deflection rates of the suspended platform, which of course depend on the dimensions of the spring steel bars restraining its response to imposed forces, are suitably small (0·0012 cm/kg in the vertical (FV) axis, and 0·0018 cm/kg in the two horizontal axes), so that a subject performing powerful muscular operations on the platform scarcely appreciates any actual movement at his feet. This stiffness also confers moderately high natural frequency and low response time characteristics on the platform. The response time, with a subject weighing about 70 kg on the platform, is of the order of 0·02 sec along all three axes. Deflections of the platform are independently damped, hydraulically, along all three rectilinear axes, the damping being optimal (that is, about 0·6 of critical damping).

The grasp transducer bar (see Fig. 1) analyses the force exerted at the hands along two rectilinear axes only, HV and HH, these corresponding respectively to the FV and FH axes of the platform (see Fig. 2). The height of the transducer bar can be adjusted, relative to the surface of the platform, along two vertical rails, the transducer bar being maintained horizontal by a system of chains (not indicated in Fig. 1). The centre of the transducer bar, to which the grasping bar (or other grasping device) is attached, is rigid. At each end of the rigid centre are attached the right and left transducer systems. Each transducer system consists of two spring steel bars, each 6·0 × 1·5 × 0·2 in., which are incorporated in the grasp transducer bar in a manner indicated in Fig. 3. It will be clear from this diagram that a force exerted on the centre of the transducer bar along the HH axis (Fig. 2) will produce appreciable bending of the inner pair of spring steel bars only. The total bending of the pair of bars will be proportional to the HH force, wherever along the transducer bar centre this force is exerted. The total bending is electrically transduced in a manner similar to that described for the FV bridge circuit. Similarly, if the sliding boxes are locked on the rails, a force HV (Fig. 2) will cause appreciable bending of the outer pair of spring steel bars, which can be electrically transduced to provide a record of the HV force. A rubber bush insert is interposed at each end of the transducer bar, between the bar and the sliding box, and this provides sufficient elastic ‘ give ’ so that the connecting blocks (Figs. 3, 5) can move in any direction, within limits, relative to the fixed sliding boxes.

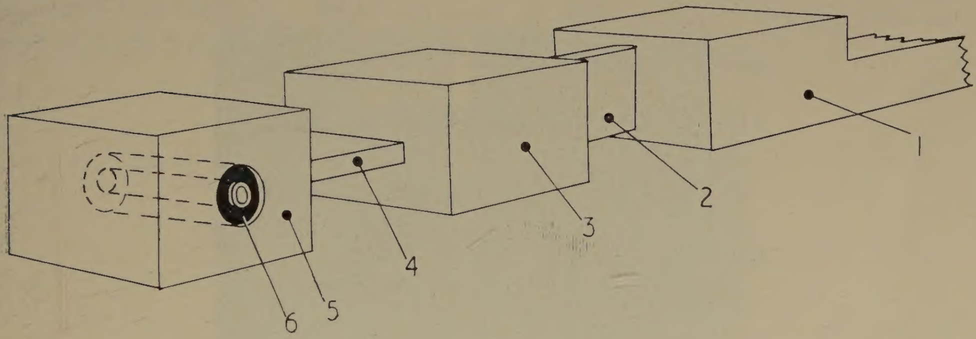

Figure 3. Left-hand end of grasp transducer bar, from same aspect as Fig. 1, but showing more mechanical detail. Fine mechanical detail (screws, etc.), strain gauges and electrical wiring omitted. Description of numbered items :—

1. Left-hand end of rigid centre of system, to which the grasping bar is attached.
2. Inner spring-steel blade, ends clamped in 1 and 3. Strain gauges mounted along the axes of the broad faces of the blade transduce the force component HH.
3. Connecting block.
4. Outer spring-steel blade, ends clamped in 3 and 5. Strain gauges mounted along the axes of the broad faces of the blade transduce the force component HV.
5. Block connecting grasp transducer system to left-hand sliding box (not shown, but see Fig. 1).
6. Rubber bush insert (‘ Silentbloc ’), providing universal coupling of system to stud on left-hand sliding box.

2.2. *Analysis of Steady Force Records*

Figure 4 illustrates the simultaneous record obtained from the platform and grasp transducer bar. Details regarding the nature of these records will be discussed later. The object of the quantitative analysis of the records was to determine the average deflection of the central two-thirds (approximately) of each record from its respective baseline. The initial and final portions of each force record were omitted from the analysis because of peculiarities of these portions which are discussed later. The central portion was considered to provide a fair indication of the performance of the subject under the specified conditions. This was accomplished by measuring, with a planimeter, the area under the central 2 cm of each record (the recording paper speed being approximately 1 cm per sec) and then dividing this area (in cm^2) by 2 cm. The average deflection in cm was then translated to its equivalent force by means of the calibration records (for platform and transducer bar) obtained at the conclusion of each series of experiments. For these calibration records the platform and transducer bar were statically loaded with known weights in the appropriate directions via a system of wires and pulleys. For the record of all four forces (FV, FH, HV, HH—Fig. 2) a sensitivity of about

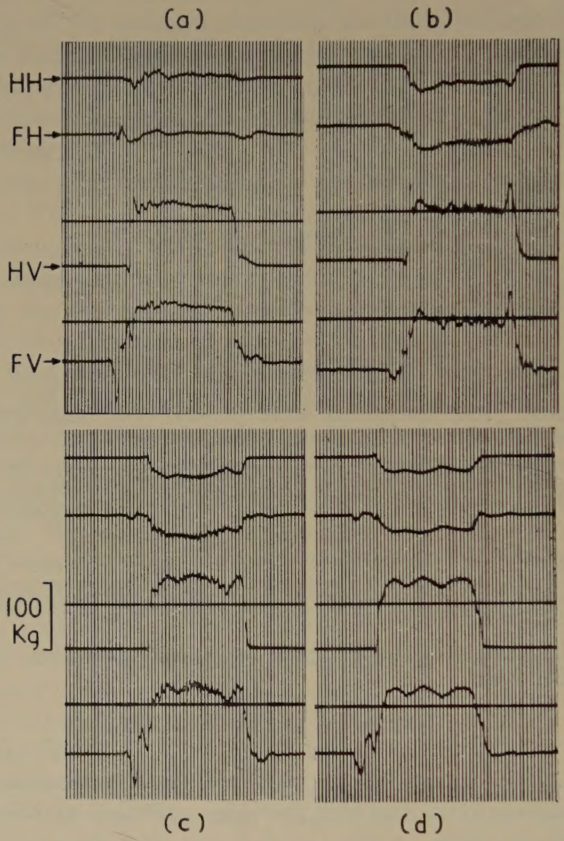

Figure 4. Four examples of simultaneous records of FV, FH, HV and HH during lifting actions. The record identification indicated for the top-left record applies to all the records. The calibration indicated against the bottom-left record (*c*) applies approximately for all records of all components of force. An up-stroke from the baseline implies: FV—force increasing in downwards direction; HV—force increasing in upwards direction; HH—force on bar increasing in direction away from the subject (i.e. push on the bar); FH—force at feet increasing towards rear edge of platform. The baselines of the records correspond to zero forces with the exception of the baseline for the FV record, which corresponds to a force equal to the static weight of the subject. The vertical time marks are at 0·1 sec intervals, 1·0 sec intervals being also indicated by slightly darker lines. For discussion of records, see text.

2 cm per 100 kg was used. The task of planimetric analysis was facilitated by use of a guiding stencil and a special planimeter setting, with which the change in planimeter reading for a particular force record gave directly the mean force, in kg, on an assumed sensitivity of 2 cm/100 kg. A simple correction to the basic planimeter reading, (derived from the calibration data for the particular record) then gave the actual force. The maximum error in deducing any single force from the record was about 1 kg.

2.3. *Subjects and Routine*

The subjects employed in these experiments were male student volunteers of age between 18 and 20 years. Certain simple anthropometric measurements were made on the subjects, of which stature and body weight are summarized in Table 2. For the lifting experiments all subjects wore shorts, singlet, thin socks and rubber-soled plimsolls, and anthropometric measurements included this clothing. Eight subjects, of statures from 172·6 to 192·3 cm and of body weights from 63·9 to 84·0 kg, were investigated.

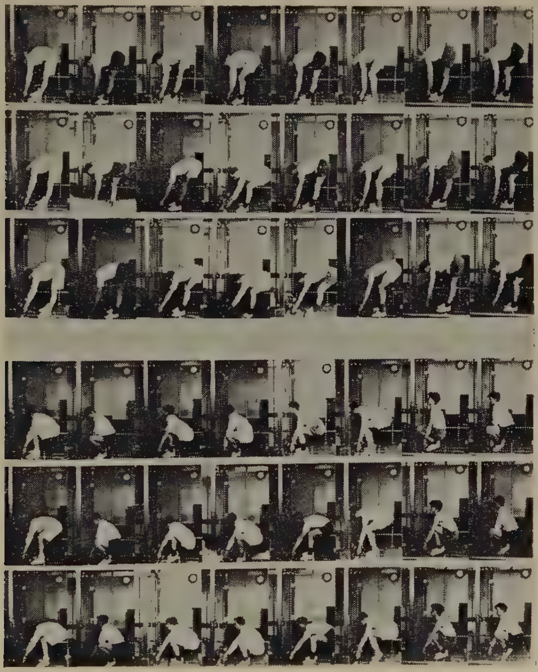

Figure 5. Collation of photographs, taken from the left-lateral aspect during lifting actions, illustrating some of the lifting postures. In each row the subjects are arranged in order of increasing stature from left to right (i.e. Subjects A, E, G, F, H, B, I, J). For the upper three rows the lifting operation is being attempted with a derrick action at an underhand grasp height of 12·5 cm. For the lower three rows a knee action is being employed at an overhand grasp height of 12·5 cm. The foot placement distance is the same for all subjects in each row, the placements for the different rows, reading from top to bottom, being 30, 40, 50, 30, 40, 50 cm respectively.

The routine of the experiments was designed to randomize with time the variables of the experiment as far as practicable. Each subject completed the whole set of lifting actions over three separate days. For the individual students these three days may have been successive days, or they may have been spread over a total period of eleven days. On each experimental day the subject performed six separate ‘ blocks ’ of lifting actions at one grasp height and two further blocks of actions at another grasp height. The six blocks of actions included all combinations of foot placement, grasp (overhand or underhand) and lifting action (derrick or knee) at the the one grasp height. Thus, over the three days, all combinations of grasp height, foot placement, grasp and action (36 different combinations of the variables in all) were completed, and certain of the combinations had been repeated on different days. Each block of lifting actions was performed at one of the three foot placements, which the subject adopted, in a standing posture, immediately after stepping on to the platform. Each block comprised two pairs of steady lifting actions (one pair overhand grasp, one pair underhand grasp), alternated with two pairs of lifting jerks (also one pair overhand and one pair underhand grasp). The results for the lifting jerks are not discussed further in this paper, and are only mentioned here to indicate the routine adopted. All steady lifting actions and lifting jerks in one block were performed with either the derrick or the knee action. The performance of the block of lifting operations was time controlled, and occupied 2 minutes. A pair of subjects alternated in the performance of a block of lifting operations, so that for each subject 2 min work alternated with 2 min rest. Preliminary experiments indicated that no appreciable fatigue should occur with this routine. It was considered that the subjects were suitably motivated to produce their maximum performance by operating in pairs, in the manner indicated, and that the possibility of boredom was reduced by alternating short periods of maximum activity with short periods of rest. Each separate lifting operation was specified to the subject (that is, type of grasp, type of action, steady pull or jerk) immediately before its performance, and each operation started from the standing posture at the foot placement adopted for the block of operations. The actual sequence of operations was varied from block to block, four different types of 'block schedule' being employed in a randomized manner. Photographs were taken during the exertion of the steady lifting forces (see Fig. 5 for examples of collations of these photographs).

§ 3. RESULTS

The results considered here were obtained from the records of the six blocks of lifting operations (steady lifting forces only) performed at one of the grasp heights on each of the three days by each subject. They thus relate to the performance by each subject of 72 lifting operations for the 36 possible combinations of foot placement (30, 40 or 50 cm), grasp height (12·5, 25·0 or 50·0 cm), grasp type (overhand or underhand) and lifting action (derrick or knee). For the 8 subjects employed, the results discussed thus refer to the analysis for 576 separate lifting operations. The analysis for each lifting operation involved the measurement of the mean force indicated by the four simultaneous records (FV, FH, HV and HH—Fig. 2) obtained for each operation. The whole analysis thus refers to measurement of 2304 mean forces from the records.

The more obvious results of the collation of these data can be summarized as follows :

(*a*) As would be expected, on simple principles of statics, in any one lifting operation the average deflections of FV and HV from their respective baselines are equal, as also are those of FH and HH. This is generally true, within the limits of experimental error, though a small and possibly significant discrepancy arises particularly with records of the type Fig. 4 (*c*). Such records suggest that the exertion of an 'isometric' force under practical conditions cannot be considered on simple statical principles, since not even the central plateaux of the FV and HV records (or the FH and HH records) are identical. The tremor, of 8–10 c.p.s. frequency, is more apparent on the FV and FH records than it is on the HV and HH records. This subject will be referred to later in the discussion. For a consideration of the results as a whole it is adequate to consider the measurement of HV and HH only as indicating the maximum ‘ isometric ’ lifting force.

(*b*) As was explained in § 2.3 the lifting operations were duplicated in each block of operations. The difference between the duplicates was examined, and was found to be insufficiently large to warrant formal statistical treatment. for the differences, even if established statistically significant, would not be important for the considerations raised in this paper. In the further collation of results duplicates were therefore averaged. The agreement between the planimetrically derived mean forces of duplicates was frequently surprising, for the pattern of the force/time record was often quite different in the duplicates. For example, one duplicate may be of type Fig. 4 (*a*), and the other of type Fig. 4 (*d*), or one duplicate may exhibit a steadily rising force, whereas in the other the force decreased progressively during the operation. The impression gained was that, although the same amount of muscular work was done in each duplicate over the same period of time, the pattern of work output with time could be, and frequently was, different. There was no evidence for fatigue in the consideration of duplicates—if anything the second operation tended to exceed, in mean force, the first operation, though, as pointed out, the difference was uniformly small.

(*c*) The effect of type of grasp was generally small. This is illustrated in Table 1. Marked differences between overhand and underhand grasps were confined to the performance of the taller subjects using the knee action, where the difference may amount to 15 per cent in favour of the underhand grasp. At particular placements and grasp heights even larger differences were found for some subjects, and were associated with the ability of the subject, under these conditions, to brace the wrists from below with the knees during the lifting action. Such considerations are of obvious importance in practical lifting operations.

(*d*) The effect of type of lifting action (derrick or knee action) was not marked, either for the individual subject or for the subjects considered as a whole. This is also illustrated in Table 1, and little further comment is required on the data presented in this table. Formal statistical treatment of the differences indicated would seem to be unjustified.

Before considering the remaining variables, of foot placement and grasp height, it is necessary to refer to the column headed θ° in Table 1. It is clear. from the data presented for the magnitude of HH, that a purely vertical lifting force was rarely exerted during the lifting operations in these experiments, even though the subjects were continually encouraged to keep the lifting effort vertically upwards. The force was usually exerted upwards-and-backwards (towards the subject), although there were some cases of upwards-and-forwards directed forces, particularly for subjects operating with the knee action at the smaller foot placements (30 and 40 cm), and at the highest grasp height

(50 cm) investigated. The angle of the force exerted with the vertical (θ°, Fig. 2), is, of course, given by the expression :

$$\tan \theta = \mathrm{HH}/\mathrm{HV}$$

and the magnitude of the single resultant force (R) by :

$$R = \sqrt{(\mathrm{HV}^2 + \mathrm{HH}^2)}.$$

The means of the deduced values of θ° are summarized in Table 1. It will be seen that, in general, θ tends to be smaller for the knee action. There is also a suggestion that θ rises to a maximum for subjects of medium height, but this observation obviously requires confirmation on a larger sample of subjects. There were general tendencies for θ to increase with increase of foot placement distance and for θ to decrease with increase of grasp height. The general conclusion, for the range of placements and grasp heights considered, is that θ is of the order of 15°, which implies a value of HH about one-quarter of HV ($\tan 15^\circ = 0{\cdot}27$).

Table 1. Mean Values of HV, HH and θ° for all Placements and Grasp Heights

Subject	HV (kg)				HH (kg)				θ° -$\tan^{-1}$ (HH/HV) ; (O and U)	
	Derrick action		Knee action		Derrick action		Knee action			
	O	U	O	U	O	U	O	U	D	K
A	41·7	45·0	45·3	48·9	11·7	10·0	16·8	14·2	14·3°	17·4°
E	40·0	38·3	39·9	40·0	11·0	8·6	3·8	1·7	13·5°	3·2°
G	58·3	61·9	52·1	53·4	21·6	22·5	15·7	18·9	19·9°	18·4°
H	58·7	63·3	70·2	74·0	18·4	13·7	13·6	9·7	14·0°	9·4°
F	50·0	51·4	54·3	61·7	28·2	23·4	19·6	24·4	26·1°	20·8°
B	59·0	57·3	59·0	64·7	14·9	12·9	10·1	12·6	12·9°	10·4°
I	69·6	69·8	65·6	75·4	18·2	16·4	19·4	18·2	13·7°	15·2°
J	64·3	64·6	55·0	57·4	10·7	9·3	11·2	7·7	8·8°	9·6°
All	55·2	56·4	55·2	59·5	16·8	14·6	13·8	13·4	15·4°	13·1°

Notes : Subjects are listed in ascending order of stature (see Table 2).
O=Overhand grasp ; U=Underhand grasp ; D=Derrick action ; K=Knee action.
Each value quoted for HV or HH was obtained by averaging the analyses for 18 lifting-operations under 9 conditions of foot placement and grasp height.

The effects of placement and grasp height were investigated in the first instance by combining the results for all eight subjects. The results of this rough analysis are plotted in Fig. 6, which also indicates the effect of foot placement on the maximum and minimum lifting force exerted by any subject in the whole series. It will be apparent from Fig. 6 that foot placement is the most important variable affecting the magnitude of the maximum lifting force, although grasp height becomes important under certain conditions, but always less important than foot placement.

In order to investigate the influence of foot placement and grasp height in more detail it is necessary to consider the statics of the lifting operation. A formula relating HV to placement (p), grasp height (h) and the angle of lifting (θ) is developed in Appendix II. This formula is derived on the hypothesis that, in the isometric lifting operation, the moment of the lifting force about the foot pivot must be balanced, for static equilibrium, by the opposing moment developed by the body weight about the foot pivot. If the effective foot pivot is β cm in front of the experimental foot placement, and if the centre of gravity of the body weight (W kg) is considered to lie α cm behind the foot pivot for all placements and grasp heights (see Appendix II), then the maximum value of HV should be given by the expression :

$$\mathrm{HV} = W \,.\, \alpha/(p + h \tan\theta - \beta).$$

This formula implies that α and β should be constant for all subjects, with the qualification that some subjects may conceivably compensate for a low value of α by increasing, if possible, the value of β.

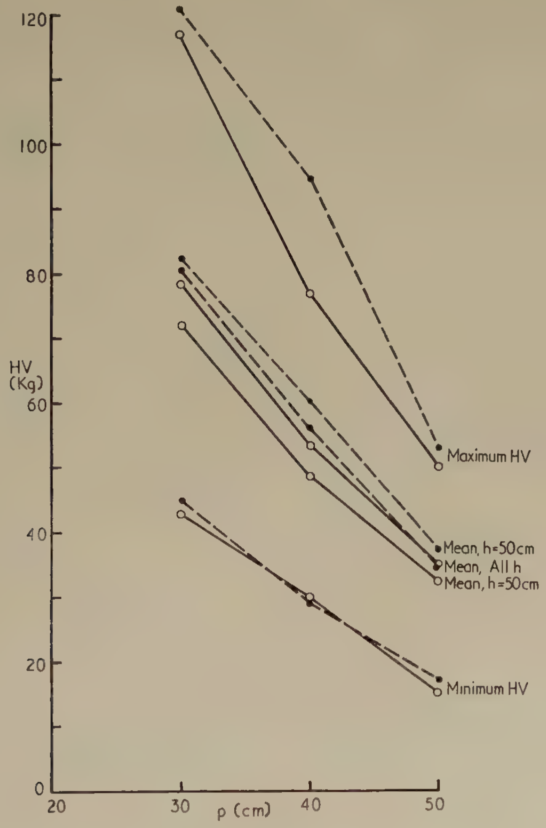

Figure 6. Variation of the vertical lifting force (HV) with foot placement distance (p). Full line, open circles—derrick lifting action ; broken line, filled circles—knee lifting action. 'Maximum HV', 'Minimum HV', and 'Mean, All h' refer to all eight subjects, the three experimental grasp heights, and the two types of grasp (overhand and underhand). The means for 50 cm grasp height only (all subjects and types of grasp) are also indicated. The experimental points have been joined up by straight lines.

The validity of this hypothesis, and of the formula just quoted, has been tested in the following manner. If the formula is true, it follows that the regression of ($p + h \tan\theta$) on 1/HV should be linear, and that an estimated value of α and β for each subject can be determined from the regression coefficients (see Appendix II). This type of analysis has been carried out on the experimental data, and the results are presented in Table 2. It may be mentioned here that the correlation coefficients of the regressions were always highly significant.

It will be apparent from Table 2 that there is quite a substantial confirmation of the hypothesis. The values of α and β tend to be similar over the investigated range of stature and body weight. Where variations of the values occur, a high value of α is typically (but not always) compensated for by a low value of β and *vice versa*. It is clear that the hypothesis developed accounts very largely, but not entirely, for the observed variation of maximum lifting force with subject, placement and grasp height. Moreover, the values obtained for β have a functional significance, for they indicate that the effective foot pivot during the exertion of a lifting force lies between 16 and 25 cm in front of the experimental foot placement. This would bring the effective foot pivot very near to, if not coincident with, the ball of the foot. The implication of this is

Table 2. Deduced Coefficients for Regression of $(p+h \tan \theta)$ on (1/HV)
(Data for Overhand and Underhand Grasp Combined)

Subject (in order of stature)	Body weight (kg)	Stature (cm)	$W\alpha$		α (cm)		β (cm)		Mean $(p+h \tan \theta)$ (experimental)		Mean HV (deduced)	
			D	K	D	K	D	K	D	K	D	K
A	63·9	172·6	969	1055	15·2	16·5	22·2	23·1	47·2	48·0	38·7	42·3
E	73·9	176·6	875	964	11·8	13·0	23·4	17·5	47·4	41·6	36·5	40·0
G	65·0	178·6	1596	1474	24·6	22·7	20·6	18·9	50·5	50·8	53·3	64·2
H	69·7	179·4	1685	1382	24·2	19·8	16·0	20·5	47·9	44·3	52·9	58·1
F	77·4	179·4	1554	1593	20·1	20·6	19·1	17·4	52·9	49·6	46·0	49·3
B	84·0	187·0	1489	1095	17·7	13·0	18·0	20·7	46·6	44·2	52·7	46·5
I	77·8	188·4	1357	1348	17·4	17·3	24·5	25·3	47·3	46·3	59·2	64·1
J	82·0	192·3	1310	1060	16·0	12·9	21·3	23·1	45·1	45·2	55·0	48·0
All Subj.	74·2	181·8	1493	1449	20·1	19·5	17·9	17·2	47·8	45·7	49·8	50·9

Notes: 1. Regression deduced by averaging HV (not 1/HV) over subjects for each placement–grasp height.

2. Symbols: HV, vertical component of lifting force (kg); $W\alpha$, body weight moment resisting lifting force moment (kg cm); p, foot placement (cm); h, grasp height (cm); θ, angle (°) of lifting force with vertical; D, derrick action; K, knee action.

3. Equation investigated:

$$\mathrm{HV} = \frac{W\alpha}{(p+h \tan \theta)-\beta}.$$

For all subjects and both actions:

$$\mathrm{HV} = \frac{19{\cdot}8}{(p+0{\cdot}26h-17{\cdot}5)}$$

(mean $\theta = 14{\cdot}6°$).

4. The right-hand two pairs of columns give the average experimental values of $(p+h \tan \theta)$ for each subject, and the corresponding values of HV according to the regression equations. It should be noted that these values of HV differ from the mean experimental values obtained from Table 1 (by averaging over the two types of grasp) solely because the deduced values imply the averaging of (1/HV), whereas in Table 1 the figures quoted were obtained by averaging HV.

5. Calculation of regressions for both derrick and knee actions in the case of Subject E omitted data for foot placement 50 cm, grasp height 25 cm (see discussion in text under § 3).

that lifting effort is normally attended by a plantar flexion effort (gastrocnemius and soleus activity) tending to lift the heels off the ground. This action was frequently very obvious during the experiments (see Fig. 5), though it will be appreciated that the effective foot pivot could move forward in this way without visible lifting of the heels.

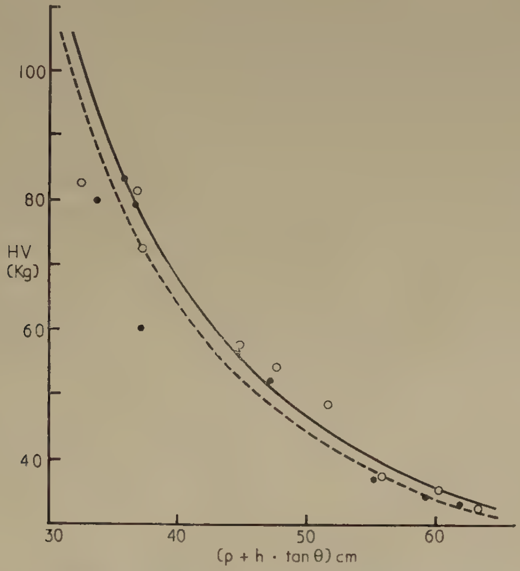

Figure 7. Variation of vertical lifting force (HV) with $(p+h \tan \theta)$. Experimental points, each based on 32 separate lifting actions by 8 subjects, open circles—derrick lifting action, filled circles—knee lifting action. The curves are those fitted to all the data for each type of lifting action (full line—derrick action, broken line—knee action), according to the hypothetical relationship :

$$\mathrm{HV} = W\alpha/(p+h \tan \theta - \beta),$$

$(W\alpha)$ being assumed constant for all subjects (1493 for derrick action and 1449 for knee action), and (β) assumed constant for all subjects (17·9 for derrick action and 17·2 for knee action). For further discussion see text.

General departures from the hypothesis have been considered by plotting the mean results for all subjects together with the deduced curves based on the hypothesis (Fig. 7). In considering Fig. 7, it should be remembered that the deduced curves are those which provide the best fit of the data to an expression of the type demanded by the hypothesis. Certain departures of the individual experimental points (each of which is based on 32 lifting operations by 8 subjects) seem to deserve comment :—

(*a*) At the smaller values of $(p+h \tan \theta)$ the observed maximum lifting force tends to fall considerably below the level expected by the hypothesis. This discrepancy, which, of course, will be largely associated with small foot placements, was not unexpected in formulating the hypothesis (Appendix II). The hypothesis demands that the lifting couple produced by muscular extension of the body between the grasping point and the foot pivot is never less than the opposing body weight moment—that is, that the force of muscular extension is never the limiting factor. As the value of $(p+h \tan \theta)$ decreases, a much larger HV can be balanced by the body weight moment ($W\alpha$, considered constant for a particular subject) ; and it is to be expected that at some stage the maximum force of the extending musculature will become the limiting factor, and further reduction of $(p+h \tan \theta)$ will not produce an increase in HV. The average 'useful' lower value of $(p+h \tan \theta)$ appears, from Fig. 7, to be about 37 cm. For the foot placements and grasp heights considered in the experiments this implies a foot placement (p) of 30 cm, so that the toes are just behind the frontal plane of the grasp axis. Further lifting experiments would be required to define the useful least value of $(p+h \tan \theta)$ with greater accuracy.

(*b*) At medium values of $(p+h \tan \theta)$ the observed mean values of HV are greater than the appropriate values predicted by the curves, with one exception which will be mentioned later. It is considered that the most reasonable explanation of this is that the coefficient α of the hypothetical equation is not constant for all values of p and h. It would appear from Fig. 7 that a value of $p=40$ cm favours a higher than average value of α for both derrick and knee lifting actions, with the one exception already noted. This exception is for $p=40$ cm, $h=50$ cm, knee action only. Under these conditions seven of the eight subjects produced a very much smaller value of θ than usual, and with four of the subjects θ was negative (that is, the bar was pushed away from the subject when it was pulled up). Thus the value of $(p+h \tan \theta)$ was considerably smaller than it was for the other five averages for $p=40$ cm (see Fig. 7), and the value of HV was appreciably higher, though not sufficiently high to bring it on to the deduced curve. It was apparent from the photographs taken during the lifting action that most of the subjects were able under these conditions ($p=40$, $h=50$, knee action) to brace the wrists from beneath with the knees, and that the subjects who exhibited the discrepancy took advantage of this possibility. Pressure below the wrists exerted by the knees during the lifting action would account for the negative values of θ, and since the mechanical situation was appreciably different from that considered in the hypothesis of Appendix II, the large departure from the hypothesis is not surprising.

(*c*) At high values of $(p+h \tan \theta)$ the agreement of the experimental data, with curves fitted on the basis of the counterbalance hypothesis, was considered to be good. There obviously must be an upper limit of p beyond which counterbalance is no longer possible because of the necessity to reach forward to grasp the load—a procedure which would eventually place the centre of gravity of the body immediately over the foot pivot. It would appear that this upper limit was not, in general, reached in the experiments under discussion. There was an indication for one subject, however, that this upper limit was being approached at foot placement 50 cm and grasp height 25 cm. Under these conditions Subject E exerted exceptionally small slifting force in both derrick and knee actions. As pointed out in Note 5, Table 2, data at this placement and grasp height for Subject E were omitted in calculating regressions for this subject. The upper limit of $(p+h \tan \theta)$ for vertical lifting will obviously depend largely on the geometry of the body linkage, and further experiments at the limits of reach are obviously required before the upper limit can be defined in terms of this geometry.

§ 4. DISCUSSION

The results presented above establish the importance of counterbalance by the body weight in determining the maximum force which can be exerted at the hands during a variety of lifting operations. A corollary to this principle is that the distance of the feet from the frontal plane within which the lifting operation is attempted is normally of primary importance in determining the maximum lifting force, the height of the hands above the floor being of secondary importance. Reijs (1921), Vernon (1924) and Bedford and Warner (1937) stressed the importance of height of grasp in developing lifting forces, but none of these authors adequately describes the other conditions operating, in particular the placement of the feet. The data of Reijs (1921) do not indicate a large effect on maximum lifting force for heights of grasp between 20 cm and 70 cm.

The strength of the musculature responsible for extending the body during a lifting operation does not appear, in the results under discussion, to become a limiting factor in developing the maximum isometric lifting force except at short foot placements. In approximate terms, the strength of the musculature only becomes a limiting factor when the toes fall in front of the frontal plane including the grasping axis. In terms of foot placement, as defined in this paper, the placement must be less than 30 cm for the strength of the body musculature to become important. In most practical lifting operations, therefore, the factor of foot placement, operating via the mechanism of body weight counterbalance, will be of greatest importance. When the plane of the grasping axis is coincident with the frontal plane in which the foot pivots lie, then clearly the maximum lifting force is limited entirely by the muscular capacity for body extension. This situation appears to be attained, or closely approached, in the foot placements employed in championship weight lifting. It is difficult to envisage many practical situations where the foot pivots and grasp axis can lie in the same frontal plane.

The conclusion arrived at in the previous paragraph seems relevant to the consideration of the maximum lifting capacity of any individual. Under most practical circumstances it seems probable that the maximum steady lifting force which a man can exert will be limited by the magnitude of the counterbalancing couple ($W\alpha$) which he can make available during the lifting effort. This should clearly be directly proportional to the body weight of the man, and the results obtained in the experiments under discussion are in general accordance with this expectation. The counterbalancing couple should also be proportional to α (the distance between the frontal plane including the foot pivot and that including the centre of gravity of the body in the posture adopted during the lifting effort). Two obvious methods of increasing the magnitude of α would be : to swing the whole body backwards during the lifting effort, so that the centre of gravity of the body is at a greater distance from the frontal plane of the grasp ; secondly, to increase the magnitude of β, which essentially moves the foot pivot nearer to the plane of grasp and further from the plane of the centre of gravity (see diagram in Appendix II).

The first manoeuvre (i.e. increasing α by swaying back the body) would obviously result in an increase in θ, and is limited by at least three considerations : the necessity for the subject to reach and grasp from the specified foot placement ; the necessity (and motivation during the experiments) to exert the maximum *vertical* lifting force ; finally, the tendency for the feet to slip if the increased horizontal force due to increase of θ exceeds the frictional resistance of the feet with the ground (see Appendix II). Nevertheless it is apparent, from Table 1, that this manoeuvre was employed by all subjects to some extent, and by certain subjects to a considerable extent. It is not possible, with the available information, to explain the varying employment of the manoeuvre, but it is suggested that the manoeuvre could not be employed beyond a certain extent by the lighter subjects (e.g. A) because of the danger of foot slippage—the light weight of the subject limiting the frictional resistance to slipping—and that the manoeuvre was not so important to the heavier subjects because the heavier body provided an adequate counterbalancing moment without resort to an excessive increase of α by swinging back the body. There may be another reason why excessive increase in α was avoided. It is pointed out in Appendix II that the vertical line of action of the body weight (see Fig. 8, Appendix II) did not, on the average, fall more than 2 or 3 cm behind the ankle pivot. The body weight counterbalancing 'lever' was, in fact, largely furnished by the moving forward of the foot pivot (by attempted plantar flexion of the foot). Throughout the lifting operation, therefore, the body could readily return to the ankle pivot (by relaxing plantar flexion) and so reduce or eliminate the counterbalancing moment. In normal lifting operations the load swings towards the body when it is lifted clear of the ground and the body would then be caught off balance if the vertical line of action of the body weight fell very far behind the ankle pivot. Too large an α, produced by swinging back the body, would therefore be accompanied by the danger of instability in normal lifting operations. In the experiments under discussion it appears that this danger was still avoided, even though the subjects were aware that the grasping point would not, in fact, move.

The second manoeuvre, of increasing the magnitude of β, has the advantage of simultaneously increasing the counterbalancing moment, and reducing the moment due to the lifting force. However, Table 2 indicates that this manoeuvre was generally employed, and usually to the maximum extent—bringing the foot pivot to a region roughly coincident with the ball of the foot. Part of the observed variation of β could have been due to corresponding variation in the detailed relative dimensions of the foot, but this was not recorded for these experiments. Further experiments with the force analysis platform, in which the variation of β during the lifting effort is directly recorded, are necessary to clarify the mechanism of the plantar flexion manoeuvre. The results already obtained emphasize that the muscular extension of the body during a lifting effort is by no means limited to the trunk, hips and knees but embraces the whole lower extremities. The gastrocnemius and soleus muscles of the leg must, therefore, play an important role in weight lifting.

The operation of the counterbalancing mechanism during lifting operations was revealed in an interesting and unexpected manner in a large proportion of the force records. In these instances (see Fig. 4 (*b*) and (*c*), for examples) a peak appears at the end of the force record, immediately before it returns to the baseline. The force indicated by the apex of this peak was often considerably greater than the steady force which had been exerted during the previous three seconds. Although event markers were not employed during the experiments, it is almost certain that this peak occurred after the subject had been instructed to relax his lifting effort. The obvious explanation of the peak is that the centre of gravity of the body was considerably behind the foot pivot when the instruction to relax was obeyed, and that relaxation of the body extension preceded re-adjustment of the centre of gravity to a position nearer the foot pivot plane The subject started, therefore, to fall backwards, but this was immediately checked by actively jerking the body forwards—so producing the observed peak. Clarification of this manoeuvre obviously requires further definitive experiments.

Further brief comments on the nature of the force records can perhaps be made here. The deflections below the base line occurring on the FV (platform) record are indications of the preparatory movements made by the subject to bring the body from the normal standing posture to the specified lifting posture. In many instances the record of steady lifting force was preceded by a sharp peak, rising considerably higher than the steady plateau which was maintained during the lifting effort. The peak on the HV record was usually higher than that on the FV record. It appeared that most of the subjects under some of the conditions of lifting jerked themselves into the steady lifting operation. The possible significance of this manoeuvre will be discussed in a future paper, describing the results obtained when subjects were actually instructed to execute a lifting jerk.

A further feature of the force records was that the plateau of the record was never a simple undisturbed line. Records of the type illustrated by Fig. 4 (*a*) were comparatively rare. More commonly the plateau was undulating, exhibiting a low frequency oscillation (Fig. 4 (*d*)) of between 1 and 2 c.p.s., a higher frequency oscillation (Fig. 4 (*c*)) of 8–10 c.p.s., or a combination of both frequencies (Fig. 4 (*b*)). The high frequency oscillation was nearly always detectable and it was always more apparent (i.e. the amplitude was greater) in the FV record than it was in the HV record. On occasions the amplitude exceeded 10 kg. This oscillation during the exertion of muscular effort is probably the same phenomenon as that reported originally by Schäfer (1886), and has received more recent discussion by Hammond *et al.* (1956), and by Halliday and Redfearn (1956). The lower frequency oscillation, which was often extremely regular in the experiments under discussion, does not appear to have been noted previously. No suggestion will be made here as to its possible significance, since further experiments, employing muscular efforts of longer duration than 3 seconds, are obviously desirable.

The possible significance of these observations of the maximum isometric lifting force for actual lifting operations, in which the load is subsequently lifted, must be briefly considered. It must be admitted that it is by no means certain that a load is normally lifted by exerting on it a steady lifting force, in excess of the load weight, which is maintained during the lift. An alternative method of lifting is obviously available—namely that of applying to the load a succession of jerks, very little force being applied to the load in between the jerks. The possible advantages of such a method of lifting will be discussed in a future paper, but it is relevant to refer again here to the quite frequent occurrence, in the present experiments, of a jerk preceding the steady force. It is difficult to avoid the conclusion that the jerk mechanism is a natural method of initiating a lifting operation. The present observations, of the maximum steady lifting force, are perhaps a better indication of the maximum capacity in *holding* a load once it has been lifted clear of the ground. The importance of body weight in providing counterbalance during the exertion of muscular effort may be considered as an extension, to an essentially static operation, of some of the principles established by Gray (1956) for the participation of body weight in the locomotory activities of vertebrate animals.

§ 5. SUMMARY

1. The maximum lifting force exertable by a man under a variety of lifting conditions has been investigated on eight young male subjects.

2. The most important variable determining the maximum lifting force is the distance of the feet from the frontal plane including the grasp axis. The force decreases rapidly with increase of this distance.

3. The maximum lifting force also decreases with increase of grasp height, but the influence of grasp height is much less than that of foot placement distance.

4. None of the other variables considered, apart from subject-to-subject variation, had an appreciable effect on the maximum lifting force. In particular, lifting actions in which extensions of the knees could participate were not appreciably stronger or weaker than those actions in which the knees remained extended throughout the operation.

5. In all lifting operations the turning moment exerted on the body by the lifting effort has to be counterbalanced by an opposing moment produced by the body weight. It is suggested that in most practical lifting operations the maximum lifting force is limited by the maximum counterbalancing moment which the body weight can provide, and that only exceptionally will the inherent muscular strength of body extension be the limiting factor. This appeared to be the chief reason why the heavier subject could exert a larger maximum lifting force under specified conditions.

6. In accordance with the principle outlined in the previous paragraph, an equation can be developed, relating the maximum lifting force to the operational variables of foot placement, grasp height and body weight. This enables a reasonable estimate to be made of the maximum lifting force to be expected of a subject of known body weight under specified conditions of foot placement and grasp height.

7. The nature of the muscular activity accompanying a lifting operation, and the significance of the results obtained for practical lifting operations, is briefly discussed. In particular, the importance of the muscle action normally associated with plantar flexion of the feet is emphasized.

The author wishes to thank Sir Wilfrid Le Gros Clark, F.R.S., in whose Department the work described in this paper was carried out, for his continual interest and assistance. Capt. D. P. Thomas, R.A.M.C., gave invaluable assistance in the analysis of the results.

APPENDIX I

DEFINITION AND DESCRIPTION OF LIFTING OPERATIONS

The primary object of any lifting operation is to do work on a mass (the load), the resistance to the operation being the force exerted on the mass by gravitation. The load is lifted when the vertical component of the force exerted by the lifter on the load exceeds the opposing vertical force due to gravity, that is, when the lifting force exceeds the product : (load mass $\times$ g). When the load mass is measured in grams, and the appropriate value of g (equal approximately to 981 cm/sec^2) is used, the force resisting lifting is obtained in dyne units. In this paper, however, the usual practical unit of force, the kg weight, will be used, one kg weight being approximately equivalent to 981 000 dynes, and written as ' kg '. Where it is necessary to use the kg unit as a unit of mass, this will be written as ' kg mass '.

Lifting operations can be carried out by Man in a variety of ways. In the majority of instances the body is applied to the load via the hands, but other parts of the body may be employed as applicators : for example, a shoulder may be placed under the load. Lifting operations employing the hands as applicators may be broadly classified by referring to the body posture with which the lifting operation is started and finished : thus different operations may be referred to as standing lifts, kneeling lifts, sitting lifts, prone lying lifts and supine lying lifts. The commonest operation is the standing lift, and this is the type of operation with which this paper is concerned.

Variables in Standing Lifts. (Lifts from the standing posture.)—The conditions for the performance of a lifting operation from the standing posture are determined by a number of variables, some of which—probably the most important—will now be considered. Some of these variables can be expressed in quantitative terms ; with others a qualitative expression of the variable is alone possible. The manner in which the body musculature is applied to lifting the load is determined by the qualitative or quantitative expression of each variable.

(i) *Type of Effort.* The lifter can be instructed to exert a steady force of controlled duration on the load or to execute a jerking action, of uncontrolled duration.

(ii) *Symmetry of Action.* In symmetrical lifting the action is confined to the sagittal plane of the lifter and the action is equally shared by the two sides of the body. A large variety of asymmetrical lifting actions are obviously possible, and no attempt will be made to detail them here.

(iii) *Symmetry of Grasp.* Essentially, this is a distinction between one- and two-handed lifting. A symmetrical action is necessarily performed by both hands similarly placed on each side of the sagittal plane of the lifter.

(iv) *Type of Grasp.* The hands can be applied to the load in a variety of ways. The following distinctions may be made :—

(*a*) *Digital or palmar stress.* In digital stressing, the lifting action tends to extend the digits which are flexed round the load—as in pulling upwards on a horizontal bar placed at a low level. In palmar stress the lifting thrust is taken on the palm of the hand or hands, so that there is a tendency for the thrust to hyper-extend the wrist—as in attempting to push upwards a horizontal bar placed at such a height that the palm can be placed under the bar. With digital stress a further distinction can be made between *open* and *closed* grasp—in the latter the hand encircles the part of the load grasped (e.g. a handle on the load) as far as possible, whereas in the former the encircling action tends to be confined to the terminal phalanges.

(*b*) *Independent or combined grasping action*, for two-handed lifting actions. In the independent two-handed grasp, the grasps of the two hands are independent—as with lifting a load provided with two handles or similar lifting points. In a combined grasping action, the grasp depends on the combined action of the two hands and arms—as in grasping a vertical cylinder placed in front of the lifter.

(*c*) *Underhand or overhand grasp.* These terms will be self-explanatory, and are defined by the degree of supination or pronation which exists when the grasp is made. Obviously, all degrees between full supination (underhand) and full pronation (overhand) can exist in practice.

(v) *Orientation of Grasp.* A wide variety of positions of the grasping axis of the hand are possible in practice. Heavy, two-handed, lifting operations are, however, most commonly made with the two grasping axes placed equidistantly on each side of the cardinal sagittal plane and equidistantly in front of the cardinal frontal plane of the lifter. The simplest orientation, which is the one adopted in this paper, is when the two grasp axes are coincident with a normal to the sagittal plane—as in making a two-handed grasp on a horizontal bar placed in a frontal plane.

(vi) *Span of Grasp*, as applicable to the symmetrical, two-handed grasp, is roughly defined as the distance apart of the hands. More precisely, it will be necessary to make the measurement in relation to stated anatomical markers. Thus the span of the grasp on a horizontal bar in the frontal plane of the lifter is defined, in this paper, as the distance between the axes of the 3rd digits of the two hands. In the case of a combined grasping action on, for example, a vertical cylinder, the span of the grasp would be defined as the diameter of the cylinder.

(vii) *Orientation of Feet.* With the standing lift the plantar surfaces of the feet constitute the only exterior contact of the body, other than the applicator (hand) surfaces. The lifting effort, for the standing lift, is therefore developed between plantar surfaces of the feet and the position of grasp. More precisely, the lifting effort for a symmetrical standing lift is developed between two axes, both axes being normal to the sagittal plane of the lifter. The *applicator axis* is a line joining corresponding points in the separate grasp axes of the two hands. The *plantar axis* is a line lying in the horizontal plane on which the lifter is standing and passing through the separate centres of pressure of the two plantar surfaces. It will be obvious that the positions of the applicator and plantar axes in space are inter-related and may be defined, for experimental purposes, as follows :—

Grasp height. This is the height of the applicator axis above the horizontal plane on which the lifter stands. For a lifting effort developed on a horizontal bar in a frontal plane, the grasp height can be accurately specified as the height in cm of the axis of the bar above the horizontal plane on which the lifter stands.

Foot placement. Ideally this should be the normal distance of the plantar axis, defined as above, from the frontal plane including the applicator axis. In lifting operations, however, the position of the plantar axis when the lifting effort is developed cannot be assumed, for any plantar flexion which accompanies the lifting operation will cause the plantar axis to move forward towards the toes. The initial foot placement is therefore specified as the normal distance in cm of the posterior contour of the heel from the frontal plane including the applicator axis. In the experiments discussed this measurement was made with the subject standing erect and wearing closely fitting plimsolls. It will be appreciated that the real plantar axis placement during the lifting effort may be as much as 30 cm less than the quoted foot placement.

(viii) *Fixation of Feet.* It will be apparent from the results discussed in the main body of the paper that a horizontal component of the predominantly vertical lifting force is normally present. The horizontal component at the feet could cause slipping. In the experiments described any such slipping was opposed only by friction between the rubber soles of the plimsolls worn and the smooth metal surface of the force analysis platform. In practical lifting operations it is very probable that slipping is obviated by such methods as bracing the toes or insteps against irregularities in the ground.

(ix) *Stance.* The stance, or distance apart of the feet, is defined as the distance between the axes of the feet at the posterior contours of the heels. The angle between the axes of the feet was left to subject preference in the experiments described, and was neither controlled nor measured.

(x) *Type of Lifting Action.* Two extreme types of lifting action are considered possible :—

Derrick action. Throughout the lifting operation the knee is kept fully extended, or even hyper-extended, and the trunk is flexed forwards (lumbar spine and hip joint flexion) so that the grasp can be made. The name given to this action is derived from its general similarity to the action of a derrick crane. The lifting effort arises from extension, or attempted extension, of the lumbar spine and hip joint.

Knee action. The grasping point is reached by folding the legs as in squatting, the trunk being maintained quite erect. The lifting effort is commonly supposed to arise predominantly from extension of the knee joint, hence the name given to the action, although extsnsion of the hip joints will obviously participate in the action.

Although a proper derrick action is possible over quite a large range of grasp heights and foot placements, the ideal knee action is only possible, for a particular subject, over a quite restricted range of heights and placements. In many cases of attempted knee actions, the trunk cannot be kept erect, but must be inclined forwards. To a less extent, some knee flexion is unavoidable when a derrick action is attempted (see Fig. 5). This arises from the situation that, when the trunk is bent forward in a derrick action, strain is perceived particularly in the hamstring tendons so that there is a strong tendency to flex the knees slightly to relieve this strain. In practice, therefore, actions intermediate between the pure knee and pure derrick actions are to be expected.

APPENDIX II

Statics of an Isometric Lifting Operation

A large number of practical lifting operations begin from the normal standing posture, and the lifting operations considered in the main text of this paper were essentially of this type. It is not proposed to discuss the nature of the standing posture here, but most investigators agree that the mechanical situation in a standing man is that the body is pivoted about the ankle joints, with the line of action of the weight of the body passing through the centre of gravity of the erect body and slightly in front of the ankle pivots. The centres of pressure of the feet on the ground are therefore located a short distance in front of the plan projection of the ankle pivot joints axis.

Before a lifting operation is attempted it is usually necessary for the body to change from the standing posture to the posture to be assumed at the beginning of the lifting operation. A common requirement is for the hands to be brought forward and downwards to grasp the load, and it is also necessary for a posture to be adopted such that a large proportion of the body musculature, particularly that of the spine and legs, can participate in the lifting operation. Lifting actions designed to further these requirements have been broadly classified as derrick and knee actions (see Appendix I).

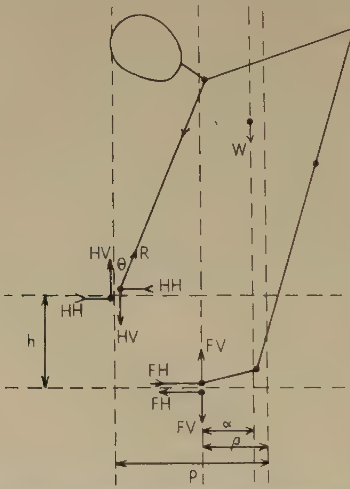

Figure 8. Diagrammatic left-lateral view of subject performing derrick lifting action, indicating the forces of action and reaction at the hands and at the feet. These points of contact are represented as being divided, to assist distinction between the actions to the exterior and the reactions on the body. Forces acting within the body linkage are not shown except *R* (the resultant of the action, or the equilibrant of the reaction, at the hands) and *W* (the body weight acting through the centre of gravity of the body parts in the lifting posture). *p* and *h* are the same as for Fig. 2. α is the leverage distance of the line of action of *W* from the effective foot pivot, and β is the distance of this pivot from the experimental foot placement.

In passing from the standing to the lifting posture there must be a considerable modification in the distribution, in space, of the masses of the different parts of the body, and this alters the position of the centre of gravity of the body parts in space. Since this operation is normally carried out smoothly, it may be assumed that the vertical line through the centre of gravity of the body (that is, the line of action of the body weight) is kept very near to the foot pivot throughout, although it must be admitted that no direct evidence is at present available to support this assumption. When the load is grasped, and the lifting effort exerted, some re-adjustment of the lifting posture could, and often visibly does, take place, and the line of action of the body weight may no longer remain near to the foot pivot. Moreover, the foot pivot itself can be expected to change its position along the axis of the foot so that the centres of pressure of the feet on the ground lie appreciably in front of the ankle joint axis. Under these circumstances dorsiflexion of the feet must be limited by plantar flexion activity of the leg musculature. The mechanical situation during the exertion of a lifting force with the derrick action is shown diagrammatically in Fig. 8. Measurements must be made in relation to known points, axes or planes in space and use is made of the experimental parameters of foot placement and grasp height (see Appendix I).

It will be clear from Fig. 8 that exertion of a lifting force with vertical and horizontal components HV and HH at the axis of grasp has the result, by operation of the law of action and reaction, that the whole body tends to be rotated about the foot axis pivot by two forces, equal in magnitude to and acting in the opposite direction from, HV and HH. The turning moment due to these forces of reaction can be opposed only by the moment due to the weight (W) of the body. Thus, if a condition of static equilibrium exists, moments taken about the foot pivot must be equal (see Fig. 8), and this equality is expressed by the equation :

$$\mathrm{HV}(p-\beta)+\mathrm{HH}\,.\,h=W\alpha \qquad \text{. . . . . . (1)}$$

where HV=vertical component of the lifting force exerted (kg), HH=horizontal component of the lifting force exerted (kg), p=experimental foot placement (cm), h=experimental grasp height (cm), α=distance of line of action of body weight behind the effective foot pivot (cm), β=distance of effective foot pivot in front of experimental foot placement line (cm) and W=body weight (kg). If θ is the angle which the resultant of HV and HH makes with the vertical, then HH=HV tan θ. It seems probable that the plane including the grasp axis and the axis joining the effective shoulder joints will also make an angle θ with the frontal plane of the subject. Substituting for HH in (i) and rearranging :

$$\mathrm{HV}=\frac{W\alpha}{[(p+h\tan\theta)-\beta]}. \qquad \text{. . . . . (2)}$$

If, for a given subject, α and β are considered to remain constant for all magnitudes of p and h then, since W is obviously constant for a given subject, the maximum vertical lifting force (HV) will decrease as p or h increase. Since the subject is attempting to lift vertically, θ can be expected to remain a small angle. Moreover, an upper limit to the value of θ will be imposed by the necessity to avoid slipping at the feet during the lifting effort. If the static coefficient of friction between the feet and the ground is μ, then slipping at the feet will occur if (reference Fig. 8) :

$$\mathrm{FH}>\mu\mathrm{FV}. \qquad \text{. . . . . (3)}$$

But FH=HH, FV=(HV+W) and tan θ=HH/HV, so that slipping will occur if :

$$\tan\theta>\mu(1+W/\mathrm{HV}) \qquad \text{. . . . . . (4)}$$

and the expression $[\mu(1+W/\mathrm{HV})-\tan\theta]$ may be regarded as the 'margin of safety', which must be greater than zero if slipping is not to occur. It will be obvious that this margin of safety decreases rapidly if the subject attempts to increase available lifting force (HV) by increasing θ to provide additional counterbalance. Thus θ will tend to be a small angle and this implies, in eqn. (2), that an absolute change in p will have a much larger effect on the magnitude of HV than the same absolute change in h would have.

The limiting effect of foot placement (p) and, to a lesser extent, of grasp height (h), on the maximum force which can be exerted by a given subject, implied by eqn. (2), assumes as has been stated, that α and β remain constant. It also assumes that the force of muscular extension of the body is always adequate to make full use of the counterbalancing moment ($W\alpha$) which is available. If, however, p and h are progressively reduced it is conceivable that a point would be reached when the force of muscular extension would be no longer adequate to make full use of the maximum counterbalancing moment available and, to maintain stability, α or β or both would have to be reduced in magnitude. It might also be expected that subjects with large body weight would always show smaller values of α and β than subjects with smaller body weight.

The investigation of the agreement of the experimental data with the hypothesis of counterbalance, summarized in eqn. (2), was carried out by examination of the regression of $(p+h \tan \theta)$ on (1/HV). This regression was calculated for the experimental data of each subject, and for the combined data of all subjects. If a and b are the regression coefficients in the usual regression equation $y=a+b(x-\bar{x})$ where $y=p+h \tan \theta$ and $x=(1/\mathrm{HV})$, α=the regression coefficient b and $\beta=a-b\bar{x}$. The results of this analysis are given and discussed in the main body of the paper.

It is perhaps unnecessary to mention that consideration of the statics of the knee lifting action leads to the same equation for HV as that developed above for the derrick lifting action.

The experimental results show that the assumption of constancy for α and β in eqn. (2) is only approximately true (see Table 2, Fig. 7 and discussion in main body of paper). If the experimental results are plotted in the form $(p+h \tan \theta)$ against 1/HV for each subject it is also clear that there must be some variation in α and β even for the same subject under different lifting conditions. The factors which might produce this variation are at present unknown, but it might be expected that the linear dimensions of the different links of the body would be involved. It is interesting to note (see Table 2, main part of paper), that the difference between α and β is not great—the average value of $(\beta-\alpha)$ for both lifting actions and all eight subjects is 3·0 cm. Thus, on the average, the line of action of the body weight is 3·0 cm in front of the foot placement line (see Fig. 8) during the lifting effort. Since the line of action of the body weight before developing the lifting force would tend to be through the ankle joint—a distance of 6 to 8 cm in front of the foot placement line—it would seem that the development of the counterbalancing moment is primarily dependent on the movement of the foot pivot forward in relation to the foot placement line. Apparently the centre of gravity of the body never moves more than 3 or 4 cm behind the ankle joint even when the maximum lifting force is being limited by inadequate counterbalance. A possible reason for this is that the normal individual appreciates (though perhaps not consciously), as a result of experience, that there are attendant dangers of instability if the line of action of the body weight is at too great a distance from the normal foot pivot—the ankle joints.

On a trouvé que la force isométrique maxima qui peut être appliquée à une barre horizontale, placée dans le plan frontal, varie, pour huit jeunes sujets mâles et différentes conditions de levage, de 15 à 120 kg. L'augmentation de la distance entre les pieds de 30 cm à 50 cm a produit la diminution maxima de la force de levage. La diminution produite par l'augmentation de la hauteur de prise de 12½ cm à 50 cm était beaucoup plus petite, et l'effet du type de la prise (par en dessus ou par en dessous) et du type de l'action de levage (avec ou sans l'extension des genoux) était en général faible. Il parait que la valeur de la force de levage est déterminée en premier lieu par la valeur du moment de la force que la masse du corps peut exercer afin de contrebalancer le réaction de la force de levage sur le corps. On discute le caractère de l'activité musculaire accompagnant cette stabilisation du corps lors des opérations de levage.

Es wurde gefunden, dass, für acht junge Männer und verschiedene Hebebedingungen, die maximale isometrische, auf einen wagerechten, in der Stirnfläche angeordneten Stab anwendbare Kraft zwischen 15 kg und 120 kg variiert. Die Vergrösserung des Fussabstandes von 30 cm auf 50 cm rief die grösste Verminderung der Hebekraft hervor. Die durch Erhöhung der Griffhöhe von 12½ cm auf 50 cm hervorgerufene Abnahme war viel kleiner, und der Einfluss der Griffart (die Hand oberhalb oder unterhalb der Last) sowie der Hebeweise (mit oder ohne Knieausbreitung) war im allgemeinen gering. Es wurde gefunden, dass die Grösse der Hebekraft hauptsächlich von der Grösse des Kraftmomentes abhängt, welches von der Körpermasse zur Anwendung gebracht werden konnte, um die Gegenwirkung der Hebekraft auf den Körper auszugleichen, Die Art der mit dieser Köperstabilisierung während der Hebearbeitsgänge verbundenen Muskelwirkung wird erörtert.

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PHYSIOLOGICAL METHODS FOR ESTIMATING THE PHYSICAL WORK CAPACITY IN WORKERS ESPECIALLY OF THE OLDER AGE GROUPS

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A submaximal test for estimating the physical work capacity has been developed and compared with a more complicated bicycle test. The testing procedure is a modified Harvard step test which in its original form is a maximal test. The pulse rate was counted during work.

The step height was 40 cm for young males and 27 cm for the older ones and for the females 33 cm; the stepping rate was 22·5 steps per min.

The average values for 'step test 40 cm', and 'bicycle test 900 kgm/min' for male subjects were: oxygen intake 2·11±0·04 and 2·15±0·02 l./min; pulse rate during work 130±1·5 and 132±1·9 beats/min respectively. The average values for 'step test 33 cm' and 'bicycle test 600 kgm/min' for female subjects were: oxygen intake 1·56±0·03 and 1·48±0·02 l./min; pulse rate during work 140±1·6 and 138±2·2 beats/min respectively. The mechanical efficiency did not vary with the body height or weight.

As the aerobic capacity for trained individuals without excessive fat is closely correlated to the body weight the light ones will be tested at a relatively higher intensity than the heavy ones, when the bicycle test is used with a fixed load. In the step test the load varies with the body weight but the oxygen intake per kilogram body weight is constant.

For estimating physical work capacity a simple, submaximal test is desirable and a modification of the Harvard step test, which in its original form is a maximal test (Johnson *et al.* 1942), has been devised. The reliability of the method should be equal to or better than that of a bicycle test. The aim of the present research was: (1) to design such a submaximal test and to compare its reliability against a working test on a Krogh bicycle ergometer, (2) to test the applicability of the method for practical use.

§ 1. Methods

The subjects were mostly students from the college of physical education in Stockholm, 29 males and 31 females between 20 and 30 years. According to earlier findings 900 kgm/min for the male students and 600 kgm/min for the female represent about 50 per cent of their working capacity (Åstrand 1952). These loads were chosen for the bicycle test, and the step test was adapted to give a corresponding load on the circulation and respiration. The height of the step was 40 cm for the males and 17 per cent lower viz. 33 cm for the females. Only 22·5 steps per min up and down the step were made. In the original Harvard step test it was 30 per min. The bicycle test was done on a Krogh bicycle ergometer with a pedal frequency of 50 per min. A step test corresponding to 600 kgm/min on the bicycle ergometer was chosen initially for the males 40–70 years old. The step was 27 cm high. The fact that 600 kgm/min on the bicycle corresponds to a step test on a bench 27 cm high for the men and 33 for the women is explained by the greater body weight of the men.

The step test was performed for 5 min and the heart rate during work was determined for 15 sec every min by palpation of the radial artery. After some training the heart rate can be determined exactly in this way; in control experiments two observers obtained the same values independently of each other. In most cases the heart rate attained a steady value after the second minute, if no steady value was obtained the last value attained was used. After work the subject sat down and the heart rate was counted over a period of 1 to $1\frac{1}{2}$ min.

Every subject fulfilled each of the tests at least three times. The average values of the heart rate during steady state and after work were calculated for every individual. The oxygen intake was determined during the last minute of work the second and third time the subject was tested.

The lactate concentration in the blood after the step test as well as after the bicycle test was low and makes it probable that the energy is delivered aerobically between the 4th and 5th min of work. Consequently a steady state is obtained and the values for oxygen intake and mechanical efficiency are reliable. To illustrate the reliability of the testing procedure the different values from the 1st, 2nd and 3rd test for 20 women subjects are given in Table 1.

Table 1[*]. Pulse rate and oxygen intake on 1st, 2nd and 3rd, days for 20 women for step test (33 cm, 22·5 steps/min) and bicycle test (frequency 50/min).

	First	Second	Third
Pulse rate during *step test*	144·4±1·7 7·5	144·7±2·4 10·4	142·1±1·9 8·3
Pulse rate 1–$1\frac{1}{2}$ min after *step test*	88·0±2·9 12·9	86·9±3·1 13·8	84·6±1·9 8·1
Pulse rate during *cycling* 600 kgm/min	139·4±2·9 12·7	140·1±3·1 13·8	140·2±2·8 12·3
Pulse rate 1–$1\frac{1}{2}$ min after *cycling* 600 kgm/min	87·5±3·0 13·2	87·4±3·4 15·1	88·9±3·3 14·5
Oxygen intake for *step test* l./min	—	1·58±0·04 1·15	1·56±0·04 0·18
Oxygen intake for *cycling* at 600 kgm/min l./min	—	1·50±0·01 0·05	1·47±0·03 0·13

§ 2. RESULTS AND DISCUSSION

The oxygen intake during the step test and the bicycle test is shown in Table 2. For the male subjects there is no statistically significant difference between the values for 'step test 40 cm' and 'bicycle test 900 kgm/min, 2·11 and 2·15 litres O_2-intake/min. For the females 'step test 33 cm' and 'bicycle test 600 kgm/min' the difference is almost significant, 1·56 and 1·48 respectively. This difference in O_2-intake for the females is not associated with any significant difference in heart rate during work. In neither males nor females is there any difference in lung ventilation or tidal air comparing step test with bicycle test.

The mechanical efficiency was determined both for step test and bicycle test. As a measure of the total energy output the oxygen intake during work was used and the basal metabolism was calculated according to the Mayo Foundation Standard, the caloric coefficient of oxygen being taken as 4·90 kcal per litre. The working intensity of the step test was calculated from the step height,

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[*] The entries in Tables 1, 2 and 4 give the mean values together with the S.E.M. and the S.D.

Table 2. Oxygen intake, total and per kg body weight, ventilation, respiratory rate, tidal air and pulse rate during and after step test (22·5 steps/min) and bicycle test (frequency 50/min) for 29 male and 31 female subjects

	Sex	O_2-intake l./min	O_2-intake per kg body weight ml./min	Vent. l./min (B.T.P.S.)	Resp. rate	Tidal air	Pulse rate during work	Pulse rate 1–1½ min after work
‘ Step test 40 cm ’	♂	2·11±0·04	30·5±0·3	43·3±0·9	19·9±0·9	2·2±0·1	130±1·5	77—1·7
		0·20	1·7	4·7	3·0	0·2	8·1	8·8
‘ Bicycle test		2·15±0·02	31·3±0·6	45·5±1·0	19·6±1·1	2·5±0·1	132±1·9	79±1·9
900 kgm/min ’	♂	0·10	2·9	5·4	3·1	0·4	10·1	10·0
‘ Step test 33 cm ’	♀	1·56±0·03	26·1±0·3	35·0±0·9	21·7±0·4	1·6±0·1	140±1·6	83±2·0
		0·15	1·4	5·0	2·0	0·3	9·0	11·1
‘ Bicycle test		1·48±0·02	25·0±0·6	35·9±0·7	22·1±0·7	1·7±0·1	138±2·2	86±2·3
600 kgm/min ’	♀	0·10	3·0	3·9	3·2	0·3	12·0	12·7

number of steps per min and the subject's body weight. The mechanical efficiency for the step test for male subjects was 16·2 and for female 15·9 per cent. The corresponding values for the bicycle test are 22·8 and 22·7 per cent. The differences in efficiency between the two sexes are not statistically significant. The efficiency for the step test is independent of the body weight, which ranged from 45·4 to 81·0 kg (Fig. 1) and independent of the body height ranging between 154 and 189 cm (Fig. 2).

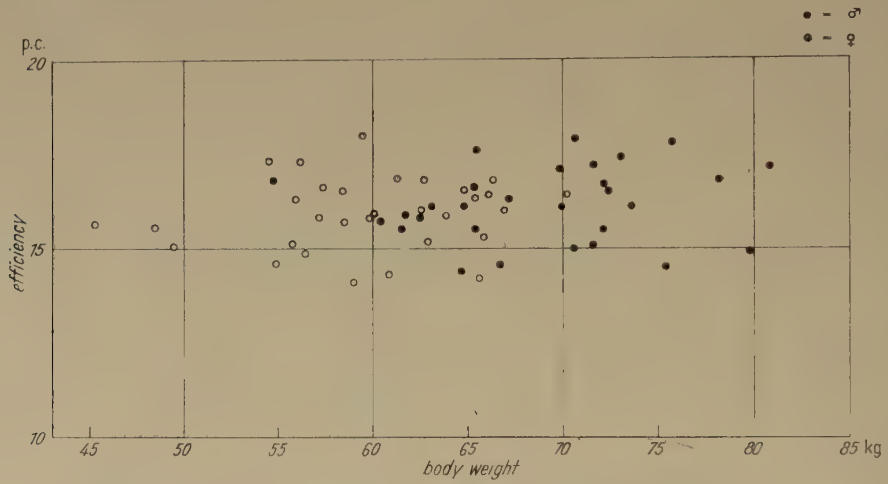

Figure 1. Step test, mechanical efficiency in relation to body weight.

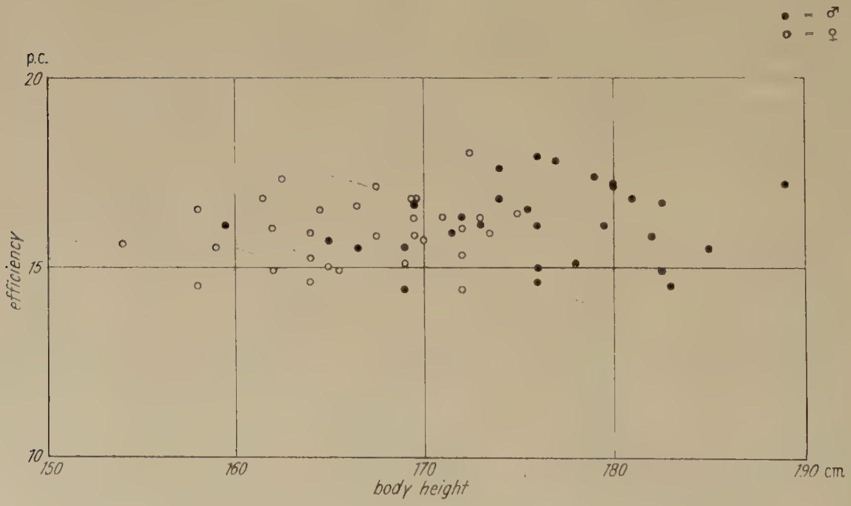

Figure 2. Step test, mechanical efficiency in relation to body height.

The average value of heart rate during ‘ step test 40 cm ’ for the male subjects is 130 beats/min, and during ‘ cycling 900 kgm/min ’ 132 beats per min. The average values after work are 77 and 79 per min respectively (Table 2). For the female subjects the average values during work are 140 per min for ‘ step test 33 cm ’ and 138 per min for ‘ bicycle test 600 kgm/min ’ and after work 83 and 86 beats/min respectively. Consequently the two types of work agree well with regard to their load on the circulation.

Less severe tests were applied to 25 males 40–65 years old. They were all workers in the tool department at Hagfors steel mill. The results (Table 3) are too few to allow any definite conclusions but a certain trend toward increasing heart rate at submaximal work load with increasing age seems to exist, indicating a definite increase in work capacity with age*.

Table 3. Pulse rate during and after step test (22·5 steps/min) and bicycle test (frequency 50/min) for 25 male subjects at Hagfors steel mill

Age	Number of Subjects	Pulse rate during ‘ step test 27 cm ’	Pulse rate 1–1½ min after ‘ step test 27 cm ’	Pulse rate during cycling 600 kgm/min	Pulse rate 1–1½ min after cycling 600 kgm/min
41–45 years	7	111	75	115	81
46–50 years	7	124	89	123	87
51–55 years	3	122	92	127	94
56–60 years	5	123	94	122	96
61–65 years	3	138	101	143	105

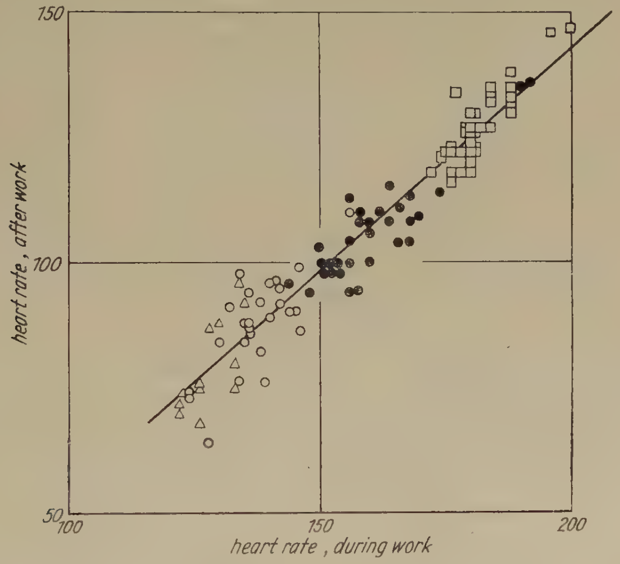

Figure 3. Pulse rate 1–1½ min after work in relation to pulse rate during work for one subject (female).

△ = step test
○ = 600 kgm/min
● = 900 kgm/min
□ = 1200 kgm/min

The individual correlation between heart rate during and after work is illustrated in Fig. 3. The values were derived from step tests and bicycle tests (600, 900 and 1200 kgm/min), representing very different training conditions of the female subject. The correlation coefficient is 0·96±0·01 and the deviation from the regression line is ±5·1 per cent. This good correlation indicates that the heart rate determined 1–1½ min after work might for one and the same subject replace the counting during work. The correlation between heart rate after and during work for the younger male and female subjects is shown in Fig. 4. The analysis includes 61 individual average values from step test and

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* See also Åstrand (1958).

Table 4. Oxygen intake and pulse rate during and after step test (40 cm) and bicycle test (900 kgm/min) for 7 male subjects 54·9–65·0 kg and 5 male subjects 75·0–81·0 kg body weight

	Step test, 22·5 steps/min				Bicycle test, frequency 50/min			
	O_2-intake l./min	O_2-intake per kg body weight ml./min	Pulse rate during work	Pulse rate 1–1½ min after work	O_2-intake l./min	O_2-intake per kg body weight ml./min	Pulse rate during work	Pulse rate 1–1½ min after work
54·9–65·0 kg	1·93±0·06 0·16	31·5±0·05 1·2	131·1±2·3 6·1	81·4±4·5 11·9	2·13±0·04 0·10	34·8±0·7 1·8	140·3±2·4 6·3	86·4±4·5 11·8
75·0–81·0 kg	2·36±0·09 0·19	30·2±1·1 2·5	134·6±2·7 5·9	80·2±4·5 9·9	2·16±0·04 0·07	27·5±0·3 0·7	130·6±3·9 8·6	79·8±4·0 9·0

66 from bicycle test. A statistical analysis of the correlation between heart rate after and during work gives the correlation coefficient 0·77±0·04 and the deviation from the regression line is ±9·7 per cent. From this data it is evident that the heart rate, 1–1½ min after work, gives only a rough idea of the heart rate during work if the results are compiled from different subjects. If the work is relatively easy, the heart rate after work will reach the normal resting values so quickly that the 1–1½ min pulse rate cannot be used for any estimation of the pulse rate during work.

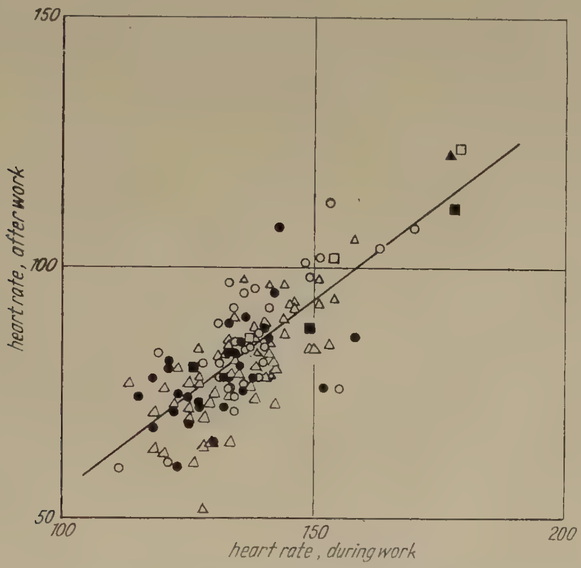

Figure 4. Pulse rate 1–1½ min after work in relation to heart rate during work. (61 individual average values from step test and 66 from bicycle test.) The symbol Δ represents step test, ●, 900 kgm/min and ○, 600 kgm/min. The symbols ■ and □ represent the average values of 15 different tests with the intensities of 600, 900 and 1200 kgm/min for two female subjects. The symbol ▲ shows the average from 6 step tests done by a male subject at 30 steps per min on a step 40 cm high.

In a step test but not in a bicycle test the work load increases with the body weight. The average values of oxygen intake and heart rate are given in Table 4 for the seven young male subjects with the lowest body weight between 54·9–65·0 kg and for the five with the highest body weight between 75·0–81·0 kg. The difference in oxygen intake for the two groups in the step test is statistically significant but this is not the case for the oxygen intake per kg body weight or for the heart rate. The corresponding values for oxygen intake in the bicycle test show no difference but the difference in oxygen intake per kg body weight is highly significant and the difference in heart rate during work is on the limit of significance. The scattering of oxygen intake l./min and ml./kg body weight and of heart rate for all subjects suggest the same relationship. If in a bicycle test the same relative stress is desired for individuals of different body weight the load should be varied with the weight of the subject.

The step test as used here is satisfactory for testing the physical fitness of healthy persons in good physical condition. For older individuals or for those less fit the intensity must be lower. For testing persons engaged in industrial work an intensity corresponding to 600 kgm/min for men and 400 kgm/min for women is suggested ; the step heights for these intensities will be 27 and 22 cm respectively.

According to earlier findings the heart rate in young healthy subjects is about the same when the same percentage of the maximal oxygen intake is taken up by the work. Consequently one should be able to calculate the aerobic capacity of a given individual if the oxygen intake and the heart rate in a certain step test are known. This is discussed in detail by Åstrand and Ryhming (1954).

A step test of the type described here could undoubtedly be a useful tool in helping to place the right man on the right job. It would also help to reveal physical insufficiency due to disease at an early stage and thereby avoid overstrain of workmen engaged in heavy manual labour.

Full details of this work were reported by Ryhming (1953).

L'épreuve sub-maximum pour évaluer l'aptitude pour le travail physique a été développée et comparée avec l'épreuve plus compliquée à bicycle. La méthode d'épreuve est une modification de l'épreuve à marche de Harvard, laquelle dans sa forme originale présente une épreuve maximum. On a compté le pouls pendant le travail.

La hauteur de la marche était de 40 cm pour les hommes jeunes, 27 cm pour les hommes plus agés et 33 cm pour les femmes ; on a escaladé les marches à une allure de 22,5 marches par minute.

Les valeurs moyennes pour ' l'épreuve à marche de 40 cm ' et ' l'épreuve à bicycle de 900 kgm ' étaient pour les hommes respectivement : consommation d'oxygène 2,11 ± 0,04 et 2,15 ± 0,02 l./min ; le pouls pendant le travail était de 130 ± 1,5 et 132 ± 1,9 battements par minute. Les valeurs moyennes pour ' l'épreuve à marche de 33 cm ' et ' l'épreuve à bicycle de 600 kgm ' pour les femmes étaient respectivement : consommation d'oxygène 1,56 ± 0,03 et 1,48 ± 0,02 l./min ; le pouls pendant le travail 140 ± 1,6 et 138 ± 2,2 battements par minute. L'efficacité mécanique n'a pas varié avec la hauteur ou les poids du corps.

Puisque la capacité aérobe pour les individus instruits n'ayant pas un excès de graisse montre une correlation avec le poids du corps, les individus legers seront examinés à une intensité relativement plus haute que les individus lourds, pendant l'épreuve à bicycle à charge constante. Dans l'épreuve à marche la charge varie avec le poids du corps, mais la consommation d'oxygène par kilogramme du poids du corps demeure constante.

Man har einen Submaximal-Test zur Schätzung der physischen Arbeitsfähigkeit ausgearbeitet und ihn mit dem mehr komplizierten Fahrradtest verglichen. Das Testverfahren ist ein abgeänderter Harvard-Stufentest, welcher in der Originalform ein Maximaltest ist. Die Pulsfrequenz wurde während der Arbeit aufgenommen.

Die Stufenhöhe betrug 40 cm für junge Männer, 27 cm für ältere Manner und 33 cm für Frauen ; die Stufen wurden mit einer Geschwindigkeit von 22,5 Stufen/min erstiegen.

Die Durchschnittswerte für den 40 cm-Stufentest und für den 900 kgm-Fahrradtest für Männer waren beziehungsweise : Sauerstoffeinnahme 2,11 ± 0,04 und 2,15 ± 0,02 l./min ; Pulsfrequenz während der Arbeit 130 ± 1,5 und 132 ± 1,9 Schläge/min. Die Durchschnittswerte für den 33 cm-Stufentest und den 600 kgm-Fahrradtest für Frauen waren beziehungsweise : Sauerstoffeinnahme 1,56 ± 0,03 und 1,48 ± 0,02 l./min; Pulsfrequenz während der Arbeit 140 ± 1,6 und 138 ± 2,2 Schläge/min. Die mechanische Leistungsfähigkeit änderte sich nicht mit Körperhöhe und Körpergewicht.

Da die aërobische Fähigkeit für geschulte Personen ohne übermässigen Fettgehalt eine nahe Korrelation mit dem Körpergewicht aufweist, werden die leichten Personen bei einer verhältnismässig höhere Intensität als sie schweren Personen untersucht werden, wenn der Fahrradtest mit konstanter Last angewandt wird. In dem Stufentest ändert sich die Last mit dem Körpergewicht, doch beleibt die Sauerstoffeinnahme per kg Körpergewicht konstant.

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USE OF COMPETITIVE TESTS AS A METHOD OF PERFORMANCE RESEARCH

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A series of investigations made in connection with a national competition in woodcutting are described. Examples of different ways of distributing the working time to each phase of the work are given.

The skill of the competitors was assessed by trained experts. The grading of skill showed some tendency to covariation with the energetic efficiency of work and with the performance in competition. The competitors were taller than the average Finnish males, they had longer trunk length, longer arms and legs, broader shoulders, and a larger chest. The result in the competition showed significant positive correlations with hand length, hip width, leg length, stature, body weight, and chest depth. However, with relative body measures, i.e. measures divided by stature, no significant correlations were observed.

The mean daily caloric intake of the competitors was 5460 kcal. In addition, the competitors lost weight on an average by 1·2 kg. Two of the four days of the competition were half-days only. On these, the men ate on an average 487 kcal more daily than on the full working days. 46·6 per cent of the calories were obtained from carbohydrates, 41·6 per cent from fat, and 11·8 per cent from protein. The distribution of food and fluid intake over the course of the day is described.

The energy expenditure of work was assessed at 309 to 780 kcal per cubic metre from food intake. In gasometric determinations values from 216 to 297 kcal per cubic metre were obtained. In gasometric determinations the energy expenditure varied from 5·7 to 11·1 kcal per minute.

During work, the erythrocyte count and the haemoglobin concentration of the blood decreased. The leukocytes showed changes typical of adrenocortical stimulation. A factor analysis showed that the changes of the erythrocytes were closely associated with those of the eosinophils and of the lymphocytes. The sodium and chloride concentration of thermal sweat decreased during the competition.

The practical applications of the results are discussed.

In experimentation, an attempt is made to standardize the variables other than those actually being examined. In performance research, the standardization of the motivation of the subject is one of the major difficulties. However, competitive tests are an approach in this direction. Admittedly, the performance level in such tests exceeds the normal one, tending towards the maximum possible. This fact must, of course, be considered when applying the results of competitive tests to work at the usual performance level.

Competitive tests as arranged with experienced workers afford an opportunity for the comparison of various working techniques and for comparative time and motion studies. The selection according to the performance makes it possible to study which anthropological, physiological and psychological characteristics tend to a covariation with the work performance. Further, under the influence of powerful motivation of competition, the participants will manifest many of the physiological processes associated with work in an exaggerated form, and thus working competitions are for the human physiologist an opportunity to obtain experimental material not easily otherwise available.

During recent years, working competitions for lumberjacks have been arranged in Finland on a national scale. This has been done partly for the purposes of propaganda, but also in the interests of performance research. The competitions are arranged on three levels : district competitions, county competitions, and the national finals. In 1951, 995 men took part in the district competitions, 236 best of these being selected to enter the county competitions, and again 40 best from the latter for the national finals. Approximately 200 000 men do lumber work yearly in Finland, and there is every reason to suppose that the competitors really represent the elite of the industry. The competitions last several days—in 1951 4 days. The working hours were restricted to $6\frac{1}{2}$ hr, which is the normal working day in this work during the dark winter. The first and the last days were whole working days, whereas the 2nd and 3rd day were half-days only, thus allowing each competitor an opportunity to observe the performance of his competitors. Of the 40 participants, only 32 completed the competition, eight of the competitors dropping out because of exhaustion, accidents, infections, and gastro-intestinal disturbances.

§ 1. TIME AND MOTION STUDIES

Some of the competitors were subjected to a detailed time study. For this purpose, a technique developed by Putkisto (1954) was used. This technique has certain advantages, e.g. it can be used by a single observer in the study of team work.

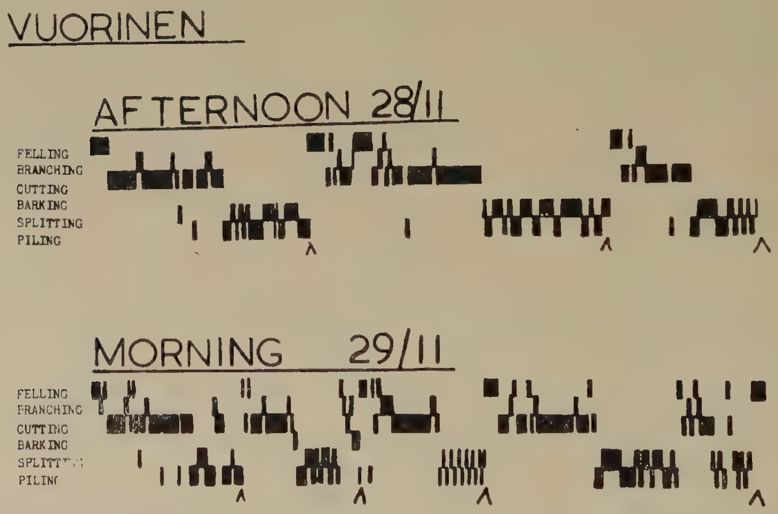

Figure 1. Typical examples of the distribution of time spent on the main phases of the work.

Some of the results obtained with the aid of this technique are presented in Figs. 1–4 worked out by Puoskari (cf. Puoskari 1955). These graphs give an easily understood picture of the way in which each competitor arranged the main phases of his work. The work starts, of course, with felling, proceeds with branching, then the trunk is cut by saw into pieces 1 metre long ; the thinner pieces are barked in strips, and the thicker ones split with an axe or two axes. The first of the graphs shows the working of the winner of the competition, Vuorinen, with a clearly organized working method. The second graph shows, as a contrast, the method the the 7th man, Ahonen, who moved from one phase of the work to another continuously, without any obvious plan. However, such a method may have been partly due to the fact that this competitor was not physically very strong; it is possible that he sought for variety in working in order to avoid purely physical fatigue due to protracted work with the same muscles and muscle groups. As an extreme in the opposite direction, the working method of Virta consisted of very long periods of each type of work (Fig. 3). This method is rarely seen

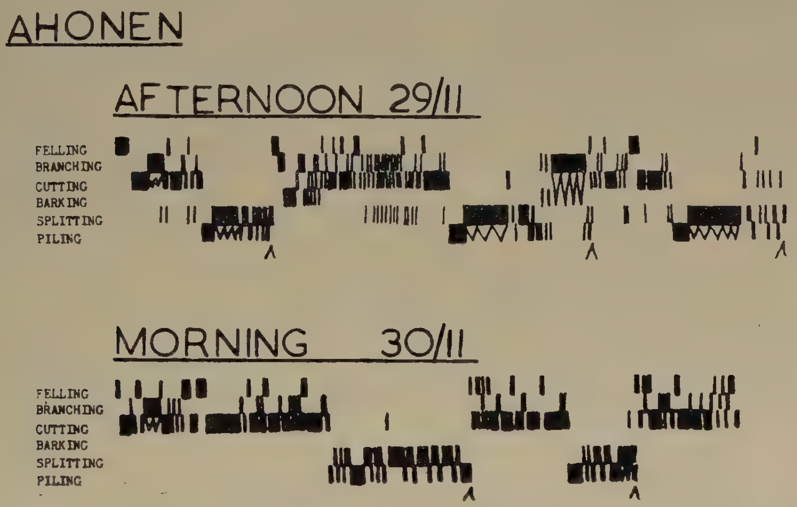

Figure 2. Typical examples of the distribution of time spent on the main phases of the work.

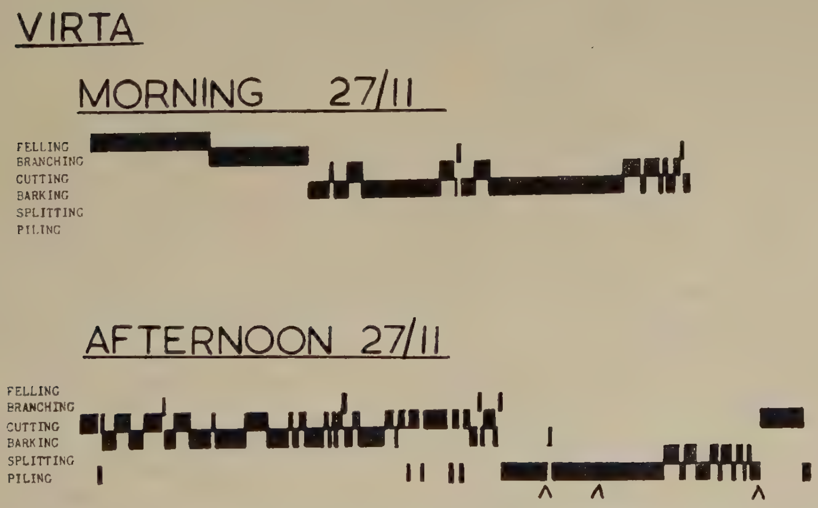

Figure 3. Typical examples of the distribution of time spent on the main phases of the work.

in normal forestry work. The graph of Montonen, the 2nd man, is characterized by a great regularity of the work with intermediate length of the periods (Fig. 4).

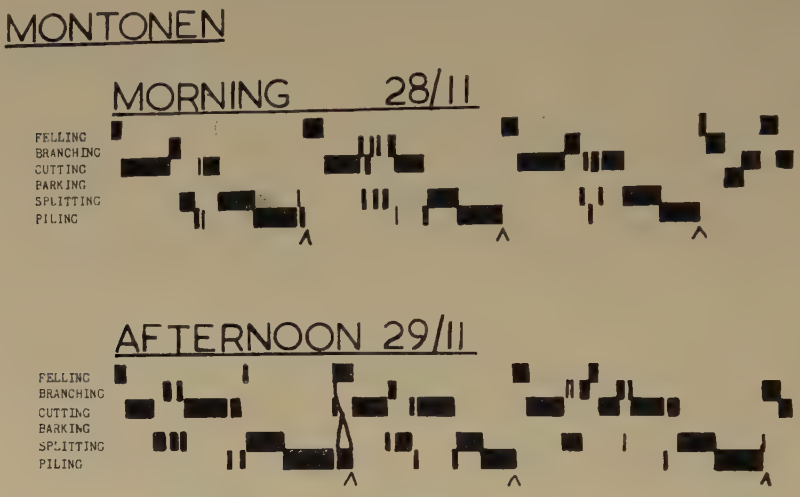

Figure 4. Typical examples of the distribution of time spent on the main phases of the work.

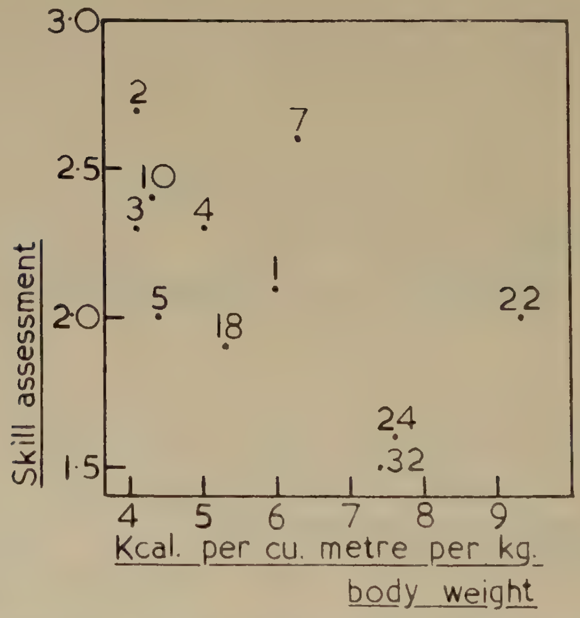

Figure 5. Mean assessment of skill as plotted against a measure of skill calculated from food intake. The numbers of the dots denote the place number of the competitor.

On the whole, these pictures show how differently even first-class workers dispose of their time in the work. These differences may be due to personal preferences, tradition, to the development of fatigue etc. The advantages and disadvantages of each type are difficult to appraise without extensive studies.

An attempt was also made to judge the skill of the same competitors who were subjected to the time study (Granvik, unpublished). For this purpose, a forestry expert and an experienced worker graded the work according to a variety of aspects. The following aspects and phases were each given a number according to a scale from zero to 3, in steps of one-quarter : *Planning* of the work, as for general planning and for planning of storage of the wood. *Felling*, as for direction of felling, danger of accidents, technical performance, physiological performance. *Branching*, as for the preparations, like cutting the trunk, for danger of accidents, and again for the technical and physiological performance. *Barking*, taking again the same four gradings as in branching. *Splitting with an axe*, with the same gradings, and *cutting with saw*, as for technical and physiological performance. An average, calculated for the gradings of each competitor, is shown in Fig. 5. The figure shows that there is some tendency for the gradings of skill to vary in parallel with efficient working, both as judged according to the result in the competition and according to the food intake. This suggests that all these basically independent measures—competitive performance, grading of skill, and a measure of efficiency based on food intake—are relevant and valuable measures of a lumberjack's performance.

§ 2. ANTHROPOMETRIC DATA

Table 1 presents a comparison of some anthropological measures of the competitors with average figures for the Finnish adult male population (Eränkö and Karvonen 1955). As a group, the competitors were taller than the average Finnish males, they had a longer trunk length, longer arms and legs, broader shoulders, and a larger chest.

Table 1. The Average Anthropological Measures of the Competitors and the Corresponding Figures for Adult Finnish Males

	Competitors cm	Finnish adult males cm
Stature	172·9	168·9
Trunk length	56·0	52·1
Leg length	91·0	89·4
Arm length	80·8	76·3
Shoulder breadth	39·0	38·3
Transverse chest breadth	30·5	28·9
Sagittal chest depth	22·1	20·3
Hip width	29·3	29·5

Each anthropological measure was also correlated with the result in the competition (Table 2). Significant correlations were found with hand length, hip width, leg length, stature, body weight, and chest depth. However, when corresponding correlations were worked out between relative body measures, i.e. measures as related to stature, no significant correlation coefficients were found. An examination of these results shows that general body size evidently is an important factor in determining the maximum work output. Particular attention is drawn to the measures of the lower body, hip width and leg length, which parts evidently play a major rôle in the work, although the tools actually are used by hand.

The result in the competition was thus to a great extent conditioned by constitutional factors. This is the more remarkable a finding, as recent studies by Telkkä *et al.* (1951) on the constitution of Finnish top class track and field athletes and wrestlers have revealed that there are less typological differences between the pursuers of the various forms of sports than has been generally believed. This difference may depend partly on the circumstance that, in our study, the men are selected from a really large group of some 200 000 active lumberjacks, whereas, in sports, the number of enthusiasts in any branch rarely rises to such high figures, suggesting therefore that success in any form of sport is determined more by interest and other similar factors.

Table 2. The Correlation Coefficients between the Result in the Competition and Various Anthropometric Measures of the Competitors. Number of Competitors: 32. Limit of Significance at the 5 per cent Probability Level: 0·349; at the 1 per cent Probability Level: 0·449.

Hand length	+0·47	Shoulder breadth	+0·27
Hip width	+0·42	Thigh circumference	+0·24
Leg length	+0·41	Hand breadth	+0·20
Stature	+0·41	Trunk length	+0·08
Weight	+0·36	Arm circumference	+0·07
Chest depth	+0·35	Chest breadth	+0·04
Arm length	+0·28		

A person's constitution is, of course, by no means adequately represented by the results of the above measurements. Many more measures, anatomical, physiological, and psychological, ought to be included in order to get a complete picture of the constitutional factors which make a man a champion lumberjack. In general, there is a promising field in the study of the factors determining a man's performance. In the field of physical exercise, Cureton (1947) has made an attempt to find out the common factors determining the performance in various activities by using the statistical method of factor analysis. The same method has been employed by Karvonen and Niemi (1953) for analysing the background of the performance of the participants of the Olympic decathlon competition. It seems that most valuable results are to be expected from the application of well-planned analytical measurements, together with statistical devices like factor analysis. Neither method alone will be sufficient for helping to define what are the ultimate factors—constitutional or others—which determine a person's performance in any special activity.

§ 3. CONSUMPTION AND SELECTION OF FOOD

The ordinary lumberjack's work is known to be the occupation showing the highest caloric consumption figures found in regular work (Tigerstedt 1900; Lundgren and Zotterman 1943). In these competitions, however, the amount of wood cut by a worker per day may amount to three times that cut by an average lumberjack. Obviously the question arises as to what extent these high production figures are achieved with the aid of an energy expenditure exceeding that of a normal lumberjack, or with the aid of better and more economical working methods. It is also to be asked whether the calories required by the competitive work can be adequately covered by food intake, or whether the high intensity of the work necessarily leads to a loss of weight.

Apart from the theoretical interest of the nutritional problems in lumberjacks' competitions, it may also be expected that a group of successful competitors may have acquired empirically food habits well suited to the conditions of heavy competitive work. These empirical habits are also worthy of study.

Food was served to the competitors according to their wishes. Each item was available *ad libitum*, and the use of additional food brought from home was also allowed. The consumption of all dishes was recorded, and the caloric values as well as the composition of the food were obtained with the aid of tables.

The mean caloric value of the food intake varied from 4120 to 7210 kcal, with a mean of 5460 kcal, among the participants who completed the competition. There was no obvious relation between the work output and the food intake. The correlation coefficient between these two sets of values was found to be $r = +0{\cdot}102$, which is not statistically significant. However, the majority of the men lost weight during the competition. The actual figures varied from a loss of 4·2 kg to a gain of 1·4 kg, with a mean loss of 1·2 kg. The loss of weight showed a positive correlation with the performance, the correlation coefficient being $r = +0{\cdot}340$,which figure approaches the limit of statistical significance (limit of significance at the 5 per cent probability level : $r = 0{\cdot}349$).

The estimation of the number of calories ascribable to changes in body weight proved difficult. There was no guarantee that a loss of weight as observed during the competition was a real loss of fat: marked disturbances in the water and electrolyte balance may well have affected the weight recorded on the morning after the competition. As a trial, the change of weight was calculated as being due to fat, and the caloric value of the loss of weight was then estimated as 8 kcal per g. When the caloric values so obtained were added to—or subtracted from—the calorie intake, values ranging from 2180 to 13 600 kcal were obtained. The average daily calorie consumption as calculated in this way was 7830 kcal. However, values like 2180 kcal are obviously absurd in conditions like these, and therefore, food intake calories only are used in further calculations, the calories covered by changes in body weight being neglected.

An attempt was made to relate the calorie consumption to the work output in a more efficient manner, by excluding the effect of variations in body size and accordingly in the basal metabolic rate. For this purpose the basal metabolic rate of each competitor was calculated with the aid of standard tables in which stature, body weight, and age are taken into account. An allowance of 50 per cent of the basal metabolic rate was added to this to cover activities other than the competitive work, and the sum was subtracted from the total daily calorie intake. This figure, which may be called the calculated net energy expenditure in work, was divided by the number of cubic metres of wood and may be regarded as a relative measure of the efficiency of the work. It appeared that generally the best competitors used the most economical technique. The correlation coefficient between the work output and the above efficiency index was found to be $r = -0{\cdot}372$, which is significant at the 5 per cent level.

In lumberjack's work, the size of the body does not affect solely the basal metabolic rate, but probably also the energy expenditure of the work. A great proportion of the work involves movements of the whole body or of substantial parts of it, and it is likely that the factor of body size has to be considered when attempting to compare the relative efficiency of men of various size. This was done by dividing the values of the net energy expenditure as based on food intake by the body weight. The calculation of the correlation coefficient between the work output and this figure gave $r = -0{\cdot}488$, a result significant at the 1 per cent level. Thus, it may be concluded that success in this working competition depended largely on the economy of the working methods.

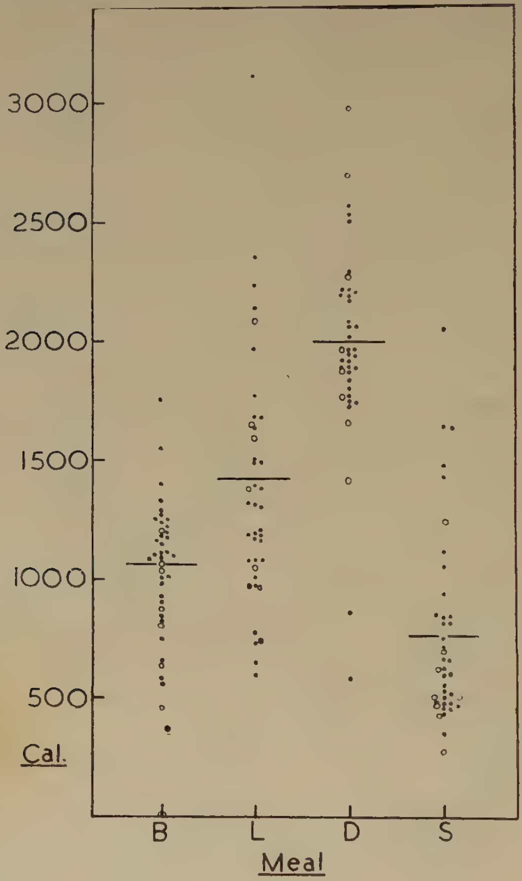

Figure 6. Mean distribution of the calorie intake during the course of the day on whole working days. B=Breakfast; L=Lunch (plus all drink and food taken during the working hours); D=Dinner; S=Supper. Dots: Competitors who completed the competition. Circles: competitors who dropped out.

When distribution of the food intake over the course of the competition was studied, it was observed that the majority of the men, 23 of 32 competitors, ate more on the half-days than on the days with full hours of work. On an average, the difference was 487 ± 855 (SD) kcal in favour of the half-days. The difference is significant at the 1 per cent probability level ($t = 3{\cdot}22$). For the best men, the difference was greatest; the difference and the work output show a positive correlation of $r = +0{\cdot}353$. These results may seem surprising at first sight. However, they are likely to have been caused by the circumstance that on the whole working days, the work itself limited the capacity of the competitor to eat, and *vice versa*. Man is able to do more work than the equivalent of some 5500 kcal per day, and man is able to eat more food than that, but evidently he cannot do both things on the same day!

The distribution of the food intake over the course of the day is shown in Fig. 6, where values for whole working days only are included. 'Breakfast' and 'Dinner' mean the actual meals, whereas 'Lunch' includes all food and drink taken during the working hours, and the term 'Supper' is used for the evening coffee or tea plus any food eventually eaten after the dinner.

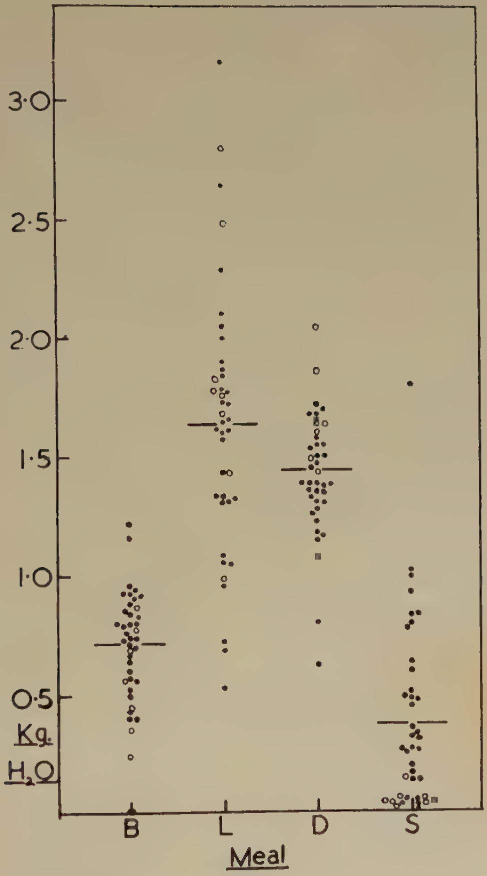

Figure 7. Mean distribution of the fluid intake (including water taken in food) during the course of the day on whole working days. For symbols see Fig. 6.

As mentioned above, the men were allowed a free selection of food, at least as far as it was practically possible. The proportions of carbohydrate, fat, and protein actually selected ± their standard deviations were: carbohydrate $46{\cdot}6 \pm 4{\cdot}0$, fat $41{\cdot}6 \pm 3{\cdot}3$, and protein $11{\cdot}8 \pm 1{\cdot}0$ per cent. The consumption of fat was considerably higher than among the general population, and the percentage of protein was on the low side, although in absolute figures the consumption of protein was not particularly low.

As a special problem, the amount of fluid taken daily was also worked out. The distribution of the fluid intake over the course of the day is shown in Fig. 7, where the values obtained during whole working days only are included. It appears from Fig. 7 that the loss of fluid is made good to a great extent during the work itself or at dinner, after which the fluid intake by drinking remains low.

It was observed as a special feature that many competitors used their own mixtures of milk and sugar or other heavily sugared drinks during the work thus combining the intake of fluid and food in a practical way. The calories consumed in this way expressed as a proportion of the total calories consumed during the lunch hour and the work itself varied widely, without any clearcut tendency according to the performance of the participant at the competition. The mean proportion was 47 per cent of the 'lunch' calorie intake. (Karvonen and Turpeinen 1954.)

§ 4. Measurement of Energy Expenditure in Actual Work

In order to check the results of the determinations of energy expenditure as based on food intake, a limited number of gasometric determinations of the work metabolism were made (Aro *et al.* unpublished). The Kofranyi–Michaelis respirometer of the Max–Planck Institut für Arbeitsphysiologie was used. In these studies, the total energy expenditure per cubic metre of wood cut varied from 283 to 355 kcal. The corresponding figures for net expenditure—after subtracting the basal metabolic rate—were from 216 to 297 kcal. These figures are lower than those obtained from the food intake : the latter figures varied from 309 to 780 kcal per cubic metre. However, the difference is not very great, and may well be due to the circumstance that for the respiratory experiments, the competitors chose an easy lot of wood, and the speed of the work was also kept slightly lower than in the actual competitive work. From the energetic aspect, the main part of the work is cutting with saw ; it may require almost half of the total energy expenditure per unit of work. Second in order of relative importance comes piling, third splitting with axe, fourth felling, and fifth branching. The total energy expenditure per minute varied from 5·7 to 11·1 kcal. In different subjects, the energy expenditure per minute showed no typical behaviour according to the phase of the work ; some men performed one phase of work with particularly high or low caloric output, whereas for others the relative order of the phases was quite different.

§ 5. Haematological Changes

Heavy muscular work is known to cause changes in the blood picture of man. There occurs a marked increase of the number of the neutrophil leukocytes and a fall of the eosinophils and lymphocytes. The monocytes and the basophils behave in a less regular manner. As to the erythrocytes, controversial findings have been published. Dehydration has obviously often affected the results. However, in this competition a statistically significant fall in the erythrocyte count and haemoglobin concentration was observed in connection with work (Karvonen and Kunnas 1952).

An attempt was made to analyse to what extent and in which way these haematological changes are correlated to each other (Karvonen and Kunnas 1953). When the change between two successive cell counts—whether it occurred over a whole working day, over a half-day, over a resting day, or over a night's rest—was taken as the unit of the calculations, a matrix of intercorrelations was obtained.

In order to express the information contained in the matrix of correlations in a clearer form, a factor analysis was performed. It resulted in the location of all the correlation coefficients in a two-dimensional space, which is shown in Fig. 8. One of the factors is represented by the horizontal, and the other by the vertical axis. The erythrocytes, eosinophils, and lymphocytes form a close cluster showing significant loadings in only one of the factors, and the segmented neutrophils are placed on the same axis, on the opposite side of zero. The second factor, on the other hand, arranges the cells of the neutrophil series according to their relative ' youth '. The monocytes and basophils have low negative loadings in this factor.

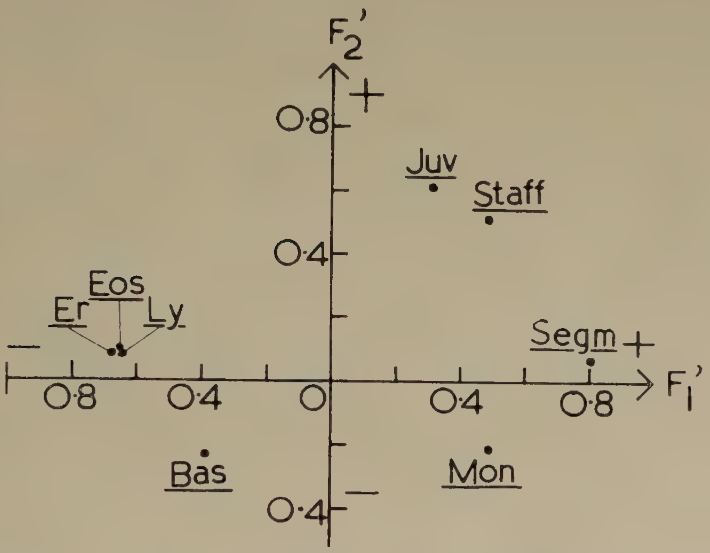

Figure 8. Final position of each blood cell type in regard to factors F_1' and F_2'. Er=erythrocytes; Eos=eosinophils; Bas=basophils; Juv=juvenile neutrophils; Staff=staff cells; Segm=segmented neutrophils; Ly=lymphocytes; Mon=monocytes.

Table 3. Factor Analysis of Haematological Changes. Communality and Uniqueness.

Cell type	Communality h^2	Uniqueness $1-h^2$
Erythrocytes	0·46	0·54
Eosinophils	0·43	0·57
Basophils	0·19	0·81
Neutrophils :		
Juvenils	0·46	0·54
Staff cells	0·48	0·52
Segmented	0·64	0·36
Lymphocytes	0·43	0·57
Monocytes	0·28	0·72

These two dimensions show only the factors common to at least two types of cells. Moreover, the variations of each type of cells are, of course, also affected by factors unique to that cell type. A measure of the relative importance of common and unique factors is given in the form of ' communality ' and ' uniqueness ', which are calculated from the loadings of each variable. They are presented in Table 3. In our case, the segmented neutrophils show the highest communality, and basophils and monocytes the lowest.

The first factor represents changes typically due to adrenocortical stimulation, i.e. eosinopenia and lymphopenia as well as a mobilization of the neutrophil leukocytes. The cause of the changes represented by the second factor, i.e. of a shift to left or right in the neutrophil series, is not equally well defined. It is interesting that the erythrocytes are so closely clustered with the eosinophils and lymphocytes. This suggests that the fall of erythrocytes in heavy muscular work is similarly caused by an adrenocortical mechanism. Further, the results of the analysis demonstrate that there are not more than two common factors which have to be considered when studying the haematological changes in heavy muscular work. Very little of this information could have been derived directly by examining the matrix of correlations.

§ 6. Composition of Thermal Sweat

Conn's studies (Conn 1949, Conn and Johnston 1944, Conn, Johnston and Louis 1946, Conn and Louis 1950, Conn, Louis and Johnston 1948) which showed that the adrenocortical hormones caused a dilution of the sodium and chloride content of thermal sweat, have given a stimulus for a series of studies on the composition of thermal sweat, as secreted in the Finnish 'Sauna' bath. It has been found that a rather wide range of sodium and chloride concentrations is to be found in persons showing a high degree of physical fitness as well as in less fit subjects (Ahlman *et al.* 1953 b). There is nevertheless some tendency to smaller values in the physically fit subjects, as in the lumberjacks. The competition itself proved to be a stimulus causing a mean daily loss of 4·5 ± 1·6 milliequivalents per litre in the sodium concentration and 3·2 ± 1·5 milliequivalents per litre in the chloride concentration (Ahlman *et al.* 1952). These changes are the more important as repeated bathing has been shown to cause, on the contrary, a rise of these values (Ahlman *et al.* 1953 a). The changes in the composition of sweat during the competition are probably also of an adrenocortical origin.

§ 7. Practical Consequences

It may be asked whether research of this kind has any practical value or whether it remains only of purely academic interest. That these results may have their practical consequences, is clearly shown by a few examples.

First, the results of the anthropometric measurements show that the measures of the *lower body* and of the *legs* to a great extent determine the working achievement among the top-class lumberjacks. Applying this finding, special stress has to be laid on the training of an efficient use of these parts of the body also in ordinary lumberjack's work. A good style in this work—or sport—is evidently characterized by a mobile body and mobile legs. The use of the arms and the upper body alone is inefficient.

Second, as the energy expenditure of normal lumberjacks rises to the same level as that found in the competition, in spite of great difference in work output, well planned *teaching of working methods* will evidently have a pronounced effect on work output in this industry, whereas increased motivation cannot alone raise the production.

Third, the application of the haematological values in the control of variations in the physical fitness, particularly as indicators of overstrain and overtraining, has already proved its value, e.g. in the health control of the Finnish Olympic skiing champions.

Fourth, valuable directives from the study of the consumption and selection of food have been obtained, which, when generally applied, have also a great inherent propaganda value because of their origin, and thus may become more easily accepted by the ordinary working man.

Finally, observations made at the competition help to define new problems of performance research and to plan their investigation.

In conclusion, it may be said that well organized competitive tests, in which the motivation is powerful enough to affect all the participants about equally, are an interesting subject for performance research and a valuable research tool.

On décrit une série d'études conduites à propos d'un concours national de coupe des bois, et l'on donne les exemples de différentes manières de répartition du temps de travail parmi les phases de travail.

L'habilité des concurrents était estimée par des spécialistes. Les classements de l'habileté avaient une tendance à covariation avec le rendement énergétique du travail et avec l'accomplissement dans le concours. Les concurrents étaient d'une taille plus haute que le Finlandais moyen, ils avaient le tronc plus long, les bras et jambes plus longues, les épaules plus larges et la poitrine plus grande. Le résultat du concours montrait des correlations positives significatives avec la longueur de la main, la largeur des hanches, la longueur des jambes, la taille, le poids du corps et la profondeur de la poitrine. Toutefois, on n'a pas observé de correlations significatives avec les mesures relatives du corps, c'est-à-dire avec les mesures divisées par la taille.

La consommation calorique journalière moyenne des concurrents s'élevait à 5460 kcal. De plus, la perte moyenne de poids des concurrents était de 1,2 kg. Des quatre jours du concours deux journées étaient des demi-jours, au cours desquels les hommes mangeaient en moyenne 487 kcal/jour plus que pendant des journées de travail complètes. 46,6 pourcent des calories provenaient des hydrates de carbone, 41,6 pourcent des matières grasses et 11,8 pourcent des protéines. On décrit la repartition de la consommation de la nourriture et des liquides au cours d'une journée.

On a évalué de la consommation de nourriture que la dépense d'énergie pendant le travail s'élevait à 309–780 kcal/m^3. Les déterminations gasométriques donnèrent des valeurs entre 216 et 297 kcal/m^3. La dépense d'énergie d'après les déterminations gasométriques variait entre 5,7 et 11,1 kcal/min.

Pendant le travail, le dénombrement d'érythrocytes et la concentration d'hémoglobine dans le sang décroissaient. Les leucocytes montraient des changements typiques pour la stimulation adrénocortique. L'analyse factorielle a montré que les changements des érythrocytes étaient associés étroitement avec ceux des éosinophiles et des lymphocytes. La concentration de sodium et de chlorure dans la sueur thermique décroissait au cours du concours.

On discute les applications pratiques des résultats obtenus.

Es wird eine im Zusammenhang mit einem Nationalholzhauerwettbewerb durchgeführte Forschungsreihe beschrieben. Es werden Beispiele verschiedener Weisen angegeben, auf welche die Arbeitszeit zwischen einzelnen Arbeitsphasen unterteilt wird.

Die Gewandtheit der Mitbewerber wurde von geschulten Sachverständigen geschätzt. Die Abstufungen der Gewandtheit zeigten einige Tendenz zur Kovarianz mit der energetischen Arbeitsleistungsfähigkeit und mit der Werkverrichtung im Wettbewerb. Die Mitbewerber waren höher gewachsen als durchschnittliche Finnen, sie hatten einen längeren Rumpf, längere Arme und Beine, breitere Schultern und grössere Brust. Das Wettbewerbergebnis zeigte signifikante positive Korrelationen mit der Handlänge, Hüftenweite, Beinlänge, Körperhöhe, Körpergewicht und Brusttiefe. Dagegen sind keine signifikanten Korrelationen mit den relativen Körperabmessungen, d.h. mit den mit Körperhöhe dividierten Körperabmessungen, beobachtet worden.

Die durchschnittliche Kalorien-Einnahme der Mitbewerber belief sich auf 5460 kcal/Tag. Ausserdem verloren die Mitbewerber durchschnittlich 1,2 kg an Gewicht. Zwei der vier Wettbewerbstage waren nur Halbtage, während welcher die Männer durchschnittlich 487 kcal/Tag mehr assen als während der ganzen Arbeitstage. 46,6 prozent der Kalorien stammten von Kohlehydraten, 41,6 prozent von Fetten und 11,8 prozent von Eiweissstoffen. Es wird die Verteilung der Nahrungs- und Flüssigkeitseinnahme im Laufe des Tages beschrieben.

Der Energieaufwand während der Arbeit wurde mit 309–780 kcal/m³ aus der Nahrungseinnahme geschätzt. Werte von 216 bis 297 kcal/m³ wurden aus gasometrischen Bestimmungen erhalten, während welcher der Energieaufwand zwischen 5,7 und 11,1 kcal/min schwankte.

Während der Arbeit verminderte sich die Erythrozytenanzahl sowie die Hämoglobinkonzentration im Blut. Die Leukozyten zeigten die für adrenocorticale Anregung typische Veränderungen. Faktorenanalyse zeigte, dass die Veränderung der Erythrozyten sehr nahe mit denen der Eosinophile und Lymphozyten verknüpft waren. Die Natrium- und Chlorid-Konzentration im wärmebedington Schweiss verminderte sich während des Wettbewerbes.

Es werden die praktischen Anwendungen der Ergebnisse erörtert.

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RESEARCH ON HUMAN FACTORS IN ROAD TRANSPORT

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The paper attempts to list the most important fields in which research on human factors in road transport is required.

The importance of improving the efficiency of road transport is emphasized, and the figures for road casualties are quoted to demonstrate the need to study the behaviour of cyclists, motor-cyclists and pedestrians as well as motorists.

The problems on which research is required are grouped under the six headings of perception, communication of information, control of the vehicle, comfort, protection of occupants, and behaviour of drivers. Subjects regarded as of particular interest are (1) the communication of information to the driver, (2) the design of the vehicle to improve control by the driver, (3) crash injury protection for the motorist and for the motor-cyclist, and (4) the study of the driving task.

About £2000 million was spent on road transport in 1954, that is, over 10 per cent of the country's income. About three times as much was spent on the transport of goods by road as by rail, and about eight times as much on passenger transport. Road accidents alone were estimated to cost about £80 million, one half of which was due to deaths and serious injuries ; about 5000 people were killed and 240 000 injured—60 000 seriously. It is clear that the road transport business will repay a large research effort to improve its efficiency.

Greater efficiency in road transport is difficult to define. It may mean the greatest safety at least cost, it may mean safer operation at higher speeds, even at higher cost. Cost depends mainly on speed and accident frequency ; higher speed reduces cost by saving time ; accidents increase cost. When road and vehicle improvements are made which result in speed increases, they frequently result in safer driving conditions and fewer accidents ; for example, improved street lighting often has this result. But increased speed may, on the other hand, be accompanied by an increase in accidents, the cost of which, however, might be less than the saving due to the speed increase. In spite of the lower cost of operation, this would be regarded by almost everyone as an undesirable change. In the rest of this paper, measures leading to a reduction of accidents or to an increase of speed will be regarded as desirable from the point of view of efficiency, and no attempt will be made to combine the effects of speed and accidents.

At the present time, research in Great Britain covers a small part only of the area in which work is urgently required on human problems in road transport. In the remainder of this paper, an attempt is made to list these problems and to pick out those which ought to be tackled first. Before doing this, however, it is of interest to examine data on traffic and accidents in Great Britain.

The trend of vehicle speeds is illustrated by measurements made on the Colnbrook By-pass in July 1954. The average speed of cars less than two years old was 51 m.p.h., that is about equal to that of cars on American roads, and it is reasonable to expect a higher and higher proportion of cars on our roads to travel at these speeds in the future. Table 1 shows the percentages of fatal and serious injuries suffered by different classes of road user in 1954. The important point to note is that, at the present time, casualties to pedestrians, cyclists and motor-cyclists far outnumber those to the occupants of motor vehicles. As the number of cars increases, casualties to occupants of motor vehicles will probably increase relatively faster than others, but, at present, it is the pedestrians, the cyclists, and the motor-cyclists who have greatest need of protection from road accidents and from their consequences.

Table 1

Built-up and Non-built-up Areas—1954

Class of road user	Number of fatal and serious injuries Built-up areas	Non-built-up areas	Total	Percentage of all fatal and serious injuries
Pedestrians	15700	2600	18300	29
Pedal-cyclists	7800	3300	11100	18
Motor-cyclists	8700	8300	17000	28
Occupants of cars, buses and commercial vehicles	7000	8800	15800	25
All classes (Total)	39200	23000	62200	100

Tables 1 and 2 illustrate two other important features of the accident situation. A greater total number of serious and fatal casualties occurs in built-up areas, that is in towns, than in country districts ; this is true for all classes of road user separately, except for occupants of four-wheeled vehicles.

Table 2

Accidents in Daylight and Darkness—1954

Light conditions	Number of fatal and serious accidents Built-up areas	Non-built-up areas
Daylight	25500	12200
Darkness	11000	6300

Table 2 is introduced to emphasize the importance of after-dark accidents in built-up areas, where in 1954 nearly twice as many serious accidents occurred after dark as in non-built-up areas. It is thus particularly important to study and make improvements in street lighting.

Problems on which research is required will now be considered.

§ 1. Perception

The driver of a vehicle must be continually on the look-out for objects—pedestrians, cyclists, other vehicles, animals and inanimate objects—in his path, or likely to cross his path, and almost all that has been done to improve the driver's view whether by night or by day has had this object—to improve the detection of objects on or near the carriageway.

Since seeing by the light of headlamps is clearly the most difficult and uncomfortable situation which the driver has to face, more effort has probably been expended in searching for improved headlamps than on any other project to improve seeing on the road. The possibilities and limitations of conventional headlamps are now fairly well understood (Harris 1954), and there appears to be little room for major design improvements. Further major advances are only likely to result if some new principle such as that of polarized light can be successfully applied. Relatively minor advances are likely to result from further researches on such things as glare, colour of light, and the distribution of light in the headlamp beam.

A great deal of attention has also been paid by lighting engineers to the improvement of street lighting, and, in this case, it can be shown more clearly than for vehicle lighting that good practice has resulted in substantial reductions in accidents. The results of a recent investigation by Tanner and Christie (1955) on the relighting of eight London streets showed an average reduction in night accidents, as judged by the ratio of night to day accidents, of 35 per cent. But relighting schemes do not always appear to be so successful, and what constitutes satisfactory street lighting is not yet fully understood. There appears to be scope for a great deal of further research, with the prospect of large savings in accidents.

An important part of future research on street lighting is the study of the patterns made by the patches of light on the road surface, which forms the background against which the driver sees objects in silhouette. The ideal for which the lighting engineer strives is a uniform bright surface, and in the past he has generally tried to do this by combining patches running along the road from the lamp to the driver. This is the method of design in non-cut-off or medium angle lighting systems. In a successful installation such as that shown in Fig. 1, the result is good ; but in a poor one, the result may be as in Fig. 2. In this case the road surface is a very dark one, glare is high, and the dark patches may conceal pedestrians or cyclists. In a cut-off installation, on the other hand, the light patches extend across the road, but, unless the lamp standards are relatively close together, they are separated by dark bands (Fig. 3). It is, at present, a matter of controversy, which system gives the better result, and there is scope for research to find (1) the best pattern to reveal objects to the driver, and (2) methods of achieving the desired patterns most economically with wet and dry road surfaces. Glare is also a factor, which varies with the type of installation and must be taken into consideration, and its influence on the detection of objects has already been extensively studied (Hopkinson 1940, De Boer 1951).

The general design of vehicles to give the maximum field of view for the driver has been studied both in this country (Grime and Moore 1953) and abroad. The blind areas due to the windscreen pillars to the front and the bodywork to the rear have been mapped out both for cars and commercial vehicles and the improvements which should ideally be made are well understood. Improvements in practice can only come as the result of action by the manufacturers.

§ 2. Communication of Information

In his task of piloting his vehicle along the road, a driver or rider is continually receiving information from other vehicles and road users, from road signs and markings and from the road itself. Improvements are possible both in the channel by which this information is conveyed and in the nature of the information. They appear to be particularly important in connection with information obtained from the road itself, which enables a driver to position himself correctly with respect to the kerb or other vehicles, and to anticipate changes of road direction.

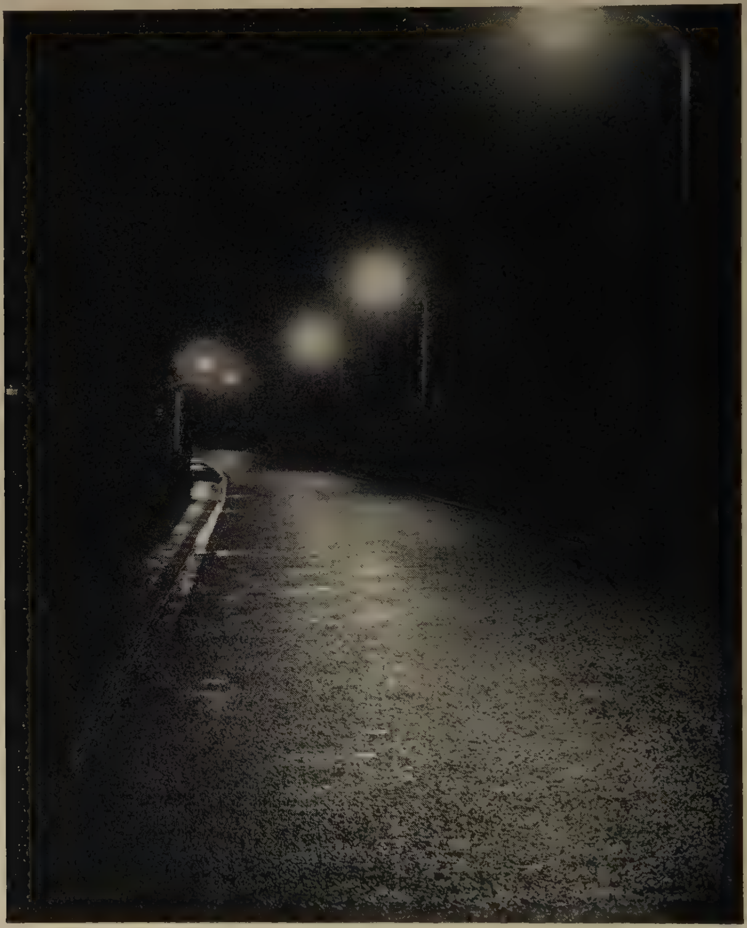

Figure 1. Non-cut-off-street lighting.

It is a matter of common knowledge that cyclists and motor-cyclists are much less inconvenienced by conditions of poor visibility than car drivers. This may be due in part to the car windscreen, but is more probably the result of the restricted field of view of the car driver, and possibly of his seat position in relation to the front wheels. An investigation to determine the ideal position and field of view for the car driver therefore appears worthwhile.

From the road itself a driver receives information mainly by observing the layout of the road, the kerb line, the hedges and houses, and the positions of lamp-posts, telegraph poles and trees. In lighted streets, the pattern of lights on and above the road surface helps or as in Fig. 4 confuses the road user. Visual clues are of enhanced importance at night, in rain or mist, and at bends and intersections. As far as I am aware, no systematic study has been made of the layout of roads as a whole from this point of view, and such a study might result in a valuable contribution to road safety.

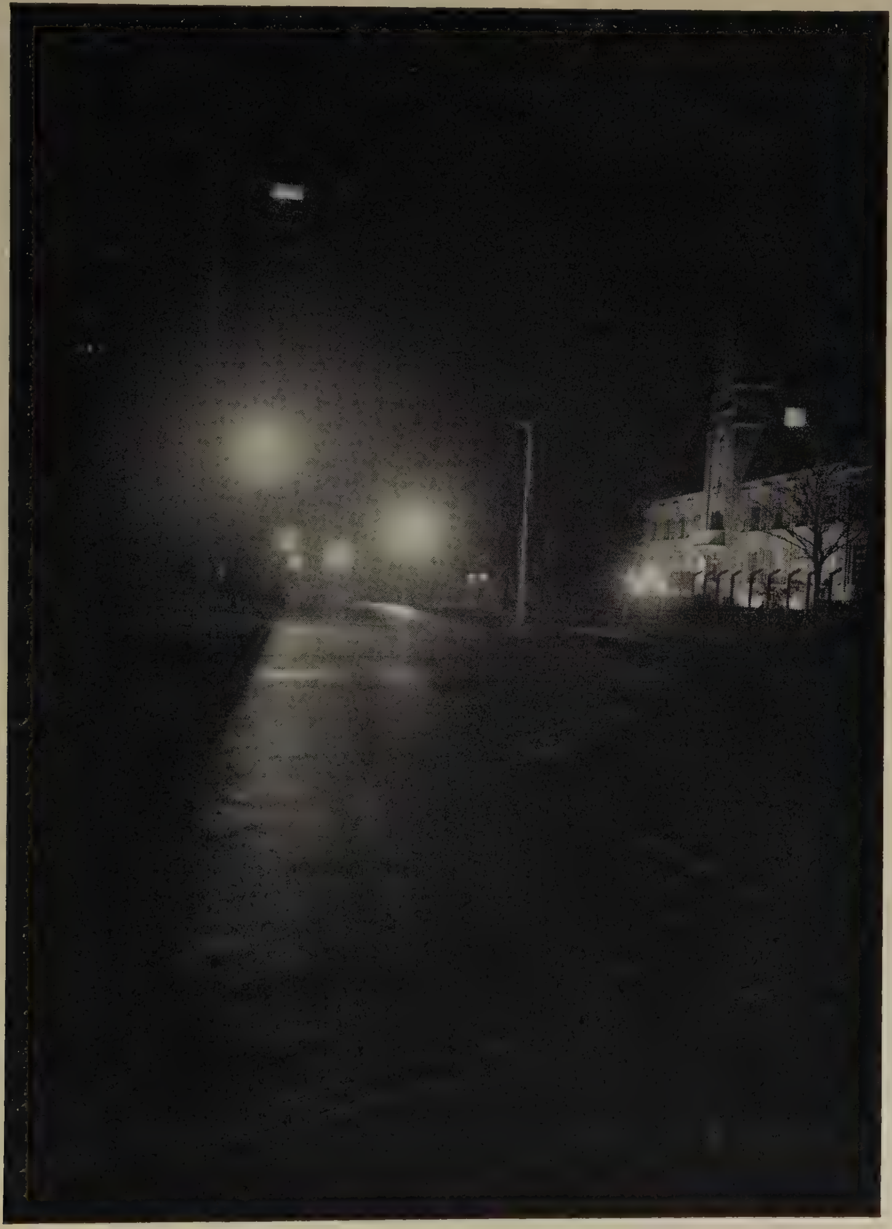

Figure 2. Poor non-cut-off street lighting. (New lamps in foreground not yet in use.)

A road carries many signs and signals to warn and instruct the driver. Traffic signs have been the subject of much experimentation (Forbes and Holmes 1939, Smyth 1947) and working rules for the legibility of signs on rural roads are emerging. But not enough is known about the time taken to absorb the information to be conveyed by signs of various degrees of complexity, particularly in town conditions, where the task of driving is so complicated. The siting of signs is another part of the investigation worthy of attention.

Warning and controlling signal lights erected on the carriageway or pavement comprise traffic lights, pedestrian-operated lights, pedestrian crossing beacons, bollards and red warning lamps. The first three are the subject of continuing research at the Road Research Laboratory.

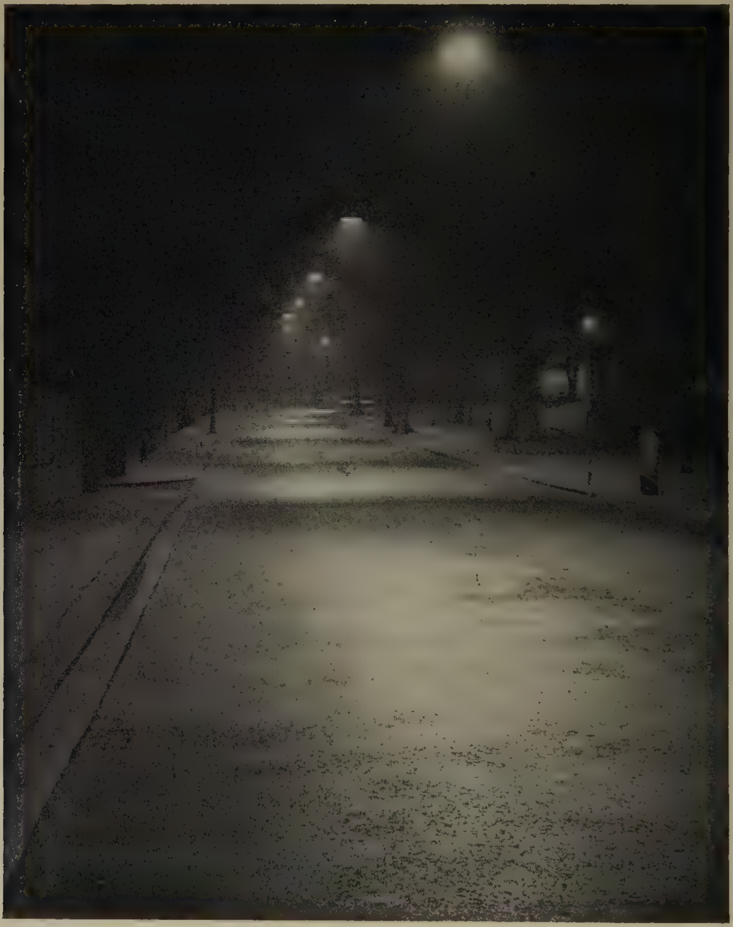

Figure 3. Cut-off street lighting.

On the vehicle, the side lights, the rear lights and the reflectors indicate the position and width of the vehicle from the front and rear, and the stop lights and direction indicators signal the driver's intentions to other road users.

Side lights have generally been considered unimportant, but their use in lighted streets, where they often afford the main indication to a pedestrian of the approach of a vehicle, would probably repay investigation. It is possible that a considerable increase in candle-power would be an advantage in these circumstances.

Rear lights have been the subject of investigations at the Road Research Laboratory (Moore 1952), in which visibility distances under normal and adverse conditions were measured from a moving vehicle, and recommendations have been made concerning light outputs. Rear reflectors have also been studied and visibility distances obtained. An investigation on the use of stop lights in convoy work was carried out some years ago by the Army Operational Research Group, and research on direction indicators has recently been in progress at the Road Research Laboratory and the Cambridge Applied Psychology Unit of the Medical Research Council. Further work on direction indicators appears to be desirable.

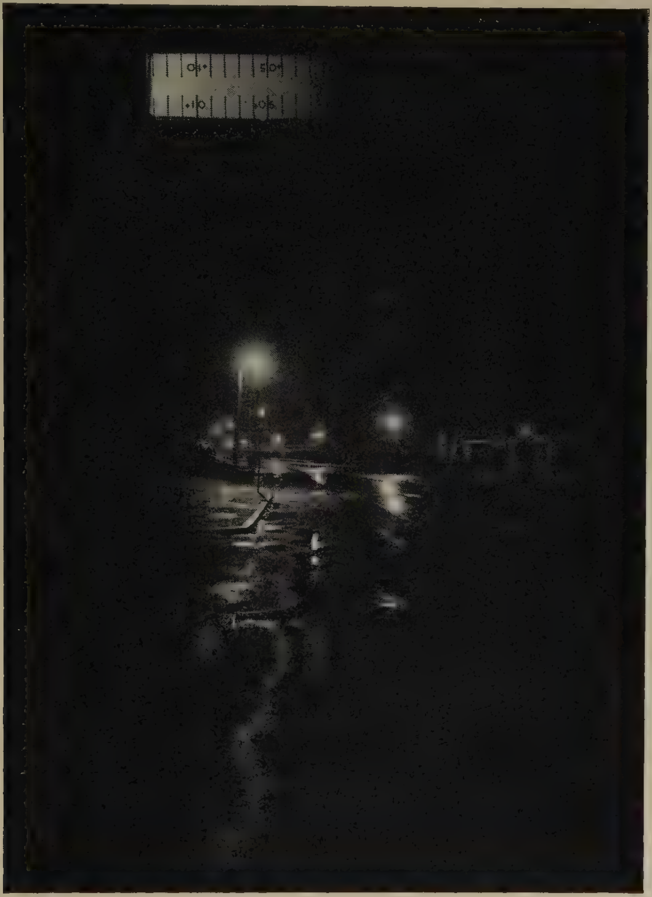

Figure 4. A confusing pattern of lights.

§ 3. Control of the Vehicle

It has been estimated (Charlesworth 1956) that the average speeds of vehicles on certain British trunk roads are increasing by about 1 mile an hour per annum, and it may therefore be expected that adequate control of the vehicle (whether motor-cycle, car, or heavy vehicle) will become of increasing importance as time passes. There are, of course, features of the mechanical design which could be improved ; for example, the weight distribution of many modern cars is such that it is difficult to avoid wheelspin during acceleration and rear wheel skidding during braking on moderately slippery surfaces ; but there is also a need to make the vehicle an easier machine to handle, by improving the control mechanisms.

A great deal of excellent work with this end in view has already been carried out on cars and commercial vehicles, particularly by MacFarland and Moseley (1954), in America, and more is required on British vehicles of all kinds. The position and type of movement of the control pedals and gear lever, the size, position and gear ratio of the steering wheel, the steering force required, the grouping and illumination of instruments, all in relation to the seated position of the driver—all have an important bearing on the driver's control of the vehicle, and will repay careful study. But it also appears that the present is an appropriate time for a more fundamental approach to the problem of the control of a vehicle. Taking the car as an example, until recently the driver had to operate all controls—the steering, clutch, brakes and gears—by his own strength. Now all controls can, if it is desired, be powered by the engine, either electrically, or by hydraulic or pneumatic mechanisms. All the old methods of control can therefore, if necessary, be discarded, and replaced by new ones designed to give the driver maximum control of his vehicle. American designers, in particular, have gone some way with automatic transmissions and clutchless cars, but it may well be that much more sweeping changes would emerge from a study which took the driver as its starting point. An alternative to the steering wheel seems highly probable, and a combined stop and go control of some kind not unlikely.

§ 4. Comfort

The most difficult problems in connection with comfort are probably still those which have received most attention—seating and springing. Too many car seats still induce numbness in an hour or two, and car sickness is still prevalent. Noise and vibration in commercial vehicles may be of importance in causing fatigue. Heating and ventilation may play a part in causing sleepiness. It has been suggested that sleepiness may also be caused by the monotony of travel on high speed roads. This may soon be a problem for British drivers, and there is scope for research on the design of roads to reduce this monotony.

§ 5. Protection of Occupants

American work (Starks 1956) on the injuries to occupants of cars involved in serious accidents has revealed that many changes in the internal design of cars are desirable in order to minimize injury in the event of accident. Similar research is required for the rather different road conditions of this country ; the injury-producing potentialities of the outside of the vehicle are also important in accidents to pedestrians and cyclists and should be studied at the same time.

The American investigations have been confined to car crashes, but in this country it is even more important to learn how to give increased protection to riders of two-wheeled vehicles, particularly motor-cyclists. Almost all deaths of motor-cyclists are due to head injury, and it is for this reason that work on the improvement of crash helmets is of such great importance. Work on this subject has recently been done at the Road Research Laboratory. The considerable progress made has chiefly resulted from work on the theory of the helmet and on the properties of shock absorbing linings. The least satisfactory part of the research concerns the mechanism of head injury, about which there is insufficient information. It is known that concussion is the most important cause of death, but from the literature only rough estimates can be made of the peak acceleration (apparently the decisive factor), necessary to produce fatal concussion. Table 3 shows how important the study of head injuries is in road safety. The chief cause of death in all road accidents is head injury, and there is little doubt that an extensive study of head injury and particularly of the mechanism of concussion would be of the utmost value. If such a study were carried out, and if it were to include, as it should, experimental work on the duration, intensity, and type of blow necessary to produce concussion, it would be essential to include a competent physicist in the team of workers, so that the difficult physical side of the subject could be adequately dealt with. A large proportion of previous work is less valuable than it might be because the physical phenomena were not understood.

Table 3

The Importance of Head Injury in Fatal Accidents—1953–54

Class of road user	Percentages of deaths due to head injury
Pedestrians	60
Pedal-cyclists	75
Motor-cyclists	80
Car occupants	50

For an equal mileage driven, a motor-cyclist is about 40 times as likely to be killed as a driver of a four-wheeled vehicle, although in terms of accidents of all kinds motor-cyclists probably have no more accidents per mile than motorists. The difference may be due largely to the fact that in an accident of any kind the rider is flung from the machine, and receives no protection from it. The increased use of bodywork on motor-cycles and, in particular, on scooters, in order to provide better streamlining or weather protection may point the way to safer motor-cycling. A fairly normal type of scooter, shown in Fig. 5 is

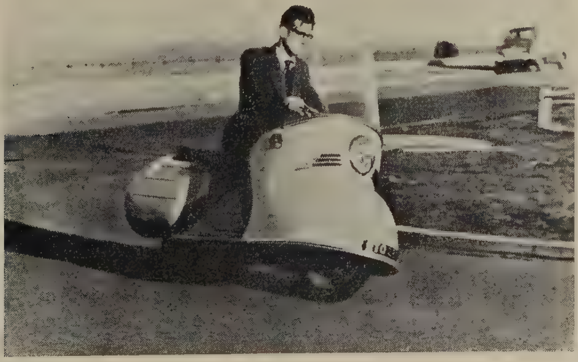

Figure 5. Motor scooter with protection for the legs.

likely to offer better leg protection than a normal motor-cycle. In a second type of motor-scooter, Fig. 6, the rider is completely enclosed in a saloon body, and it appears likely that this bodywork would afford considerable protection to the rider, and in many accidents might prevent him from being thrown from his machine. Investigations might profitably be made to find the best method of strengthening the bodywork to afford maximum protection in accidents, and also to determine whether in such a machine the rider would be less likely to suffer injury if he were tied to his machine by a safety belt.

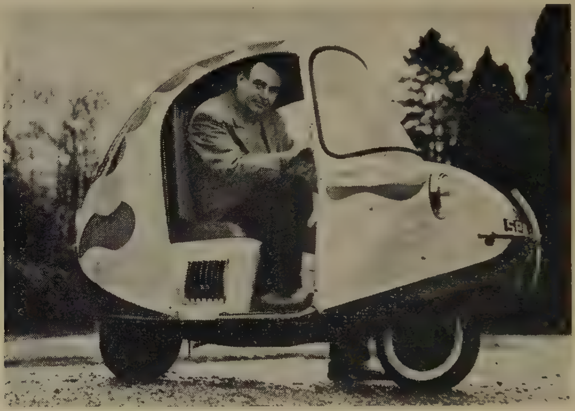

Figure 6. Motor-scooter with a saloon body.

Before leaving the subject of crash injury, reference may be made to the possibility of saving life by improvements in medical services. Gissane (1954) has estimated that improvements in the surgical treatment of serious accident cases could lessen considerably the present mortality and morbidity figures, perhaps by as much as 25 per cent.

§ 6. DRIVER CHARACTERISTICS

The importance of studying the driver and of improving his driving methods can hardly be exaggerated. There is evidence, for example, that the training of drivers can reduce accidents. Some years ago a comparison was made of the accident rates of the Police Driving School at Hendon with those of the whole Metropolitan Police Fleet. In 1948 the figures were 12 and 30 per million vehicle-miles respectively for cars and 15 and 37 for motor-cycles. The figures for the fleet as a whole are themselves low.

Other evidence comes from America, where in many high schools, courses in driver training are given as part of the normal school curriculum. In 1954, a summary of the results was issued by the American Automobile Association. After some re-working of the figures to allow for differences in exposure to risk of boys and girls, the results showed that the trained drivers had only one-half as many accidents as the untrained. The comparison is made in Table 4.

Research on the driver is conveniently considered under the headings of (1) selection, (2) training, and (3) operation. The following is a list of subjects for study. Most of these are being pursued in the United States of America, and all would repay further investigation.

Table 4

The Effect on Accidents of Training American High School Drivers—1954

Drivers	Ratio of accident rates $\frac{\text{untrained}}{\text{trained}}$
Men and boys	1·8
Women and girls	2·2

(1) *Selection*

(*a*) Physical fitness ; effect of physical defects, particularly those of eyesight.

(*b*) Psychological fitness ; the development of selection procedures.

(2) *Training*

(*a*) The study of the driving operation, and the development of methods of assessing the skill of drivers ; driving errors.

(*b*) The development of the most effective training methods, including those for the training of motor-cyclists.

(3) *Operation*

(*a*) The development of methods of following up the training of drivers ; retraining of those with poor accident records.

(*b*) Supervision of commercial drivers ; rewards and penalties for accidents.

(*c*) Police supervision of drivers.

(*d*) The effect of alcohol and drugs.

(*e*) Fatigue.

The results of the studies on selection methods are likely to lead to procedures for the rejection of drivers who are probably but not certainly bad accident risks. They are therefore applicable to commercial drivers rather than to drivers of private vehicles, but research on the training of drivers could be of universal application, and for this reason is probably the most urgent part of the programme on the driver. The rider of the two-wheeled vehicle, who is by far the most vulnerable road user on wheels, should again have priority.

§ 7. CONCLUSIONS

The main conclusions of the paper are that research work on human factors in road transport might with advantage be directed to a greater extent than at present into the following channels :

1. More work should be done on the safety of motor-cyclists ; improved training for the motor-cyclist and changes in design of the vehicle to increase safety are considered to be of great importance.

2. In seeking to improve visibility at night more attention should be paid to urban conditions ; in particular, the patterns formed at night by light and shade on the road and by the lights above it play a large part in the detection of obstacles and in the communication of information to the driver, and require investigation.

3. The controls, the seated position, and the areas of clear view of the car driver require a basic investigation starting from the driver's requirements and neglecting limitations imposed by present-day engineering.

4. Medical studies of the mechanism of head injury are urgently required.

This paper was prepared at the Road Research Laboratory of the Department of Scientific and Industrial Research, and is published by permission of the Director of Road Research.

L'auteur se propose d'énumérer les champs les plus importants dans lesquels il est nécessaire d'étudier le rôle des facteurs humains dans le transport routier.

On souligne l'importance de l'amélioration de l'efficacité du transport routier et l'on donne les chiffres des accidents de route pour démontrer la nécessité d'études sur la tenue non seulement des automobilistes mais aussi sur celle des cyclistes, motocyclistes et piétons.

Les problèmes où les études sont indispensables peuvent être groupés sous les chefs suivants : perception, communication de l'information, commande de la voiture, confort, protection des voyageurs et tenue des chauffeurs. Les sujets d'intérêt particulier sont : (1) communication d'information au chauffeur, (2) construction de la voiture, amenant l'amélioration de la commande par le chauffeur, (3) protections des chauffeurs et motocyclistes contre les blessures causées par collision, et (4) l'étude du travail de chauffeur.

Es wird versucht, die wichtigsten Gebiete zu nennen, in denen die Forschung menschlicher Faktoren im Strassentransport unentbehrlich ist.

Man hebt die Wichtigkeit der Verbesserung des Strassentransportwirkungsgrades hervor, und es werden Strassenunfälle angefürht, um zu beweisen, dass es nötig ist, nicht nur das Verhalten der Wagenführer, aber auch das der Radfahrer, Kraftradfahrer und Fussgänger zu erforschen.

Die der Forschung bedürfenden Probleme werden in sechs Gruppen zusammengebracht : Wahrnehmung, Nachrichtenmitteilung, Wagensteuerung, Bequemlichkeit, Insassenschutz und Verhalten der Wagenführer. Die folgenden Gegenstände werden als besonders interessant angesehen : (1) Mitteilung der Nachrichten dem Wagenführer, (2) Wagenkonstruktion insofern sie eine Verbesserung der Steuerung durch den Wagenführer zustande bringt, (3) Sturzverletzungsschutz für Kraftfahrer und Kraftradfahrer und (4) Studium der Wagenführungsarbeit.

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HEADLIGHT DESIGN

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A brief survey is given of the historical development of motor vehicle headlights. The principles underlying the design of the block lens headlamp used in America and Great Britain and the sharp cut-off lens used on the Continent are described and a comparison is made of the two systems.

An outline is given of the polarized headlamp system that is being investigated by the Laboratory.

§ 1. Historical

In tracing the history of motor vehicle headlighting from the oil lamp and acetylene lamp of the early part of the century to the advent of electric lighting in 1910 and its subsequent development, one is struck by the fact that the same basic lighting problem we face today was being recognized and tackled a very long time ago (Automotive lighting 1906–1956). A final solution has not yet been reached because a perfect headlight must satisfy two incompatible conditions : it must flood the road in front of the driver with light and yet at the same time must throw no glare in an opposing driver's eyes.

The earliest electric headlamps were small searchlights which produced, by the aid of a parabolic reflector, a powerful but narrow beam suitable for driving on the open roads of those days when encounters with other vehicles were rare, but with the increase in traffic after World War I the problem of glaring lights and dazzled drivers first made its appearance. By 1922 it was of sufficient importance to merit a special report by the Optical Society (1922). The first major step forward in headlight practice took place in the middle twenties with the adoption of the now familiar two-beam system. The main, or upper beam, designed to throw maximum light on the road ahead, was intended for open-road driving, while a dipped, or passing beam aimed some 3° below the horizontal was used when encountering other vehicles to reduce the light reaching an oncoming driver's eyes. The American designers used a two-filament lamp to produce the two beams, a filament at the focus for the main beam and a filament mounted above and slightly to one side for the dipped beam. In Great Britain in the 1930's designers favoured a movable reflector assembly which was tilted downwards and to the nearside by means of an electromagnet operated by a switch under the control of the driver ; this operation also switched off the offside headlamp.

The next major advance was made in America with the introduction of a sealed lamp. In earlier lamps the bulb had to be inserted from the front of the lamp and the focusing was frequently left to chance. The seal between headlamp glass and reflector was made by means of gaskets which were not proof against the ingress of moisture and dirt so that eventually lamp reflectors and thus lamp output deteriorated. The ' sealed ' beam lamp is, in effect, a large gas-filled bulb with a built-in reflector and lens which is impervious to dirt or atmospheric corrosion. The position of the filament and hence the focusing of the lamp is fixed in manufacture, thus eliminating another possible variation. A disadvantage of the sealed beam unit is that if a filament fails the whole unit has to be thrown away. British manufacturers have now followed the American system of using a second filament for obtaining the dipped beam, but instead of a sealed unit they use an integral reflector and lens unit and insert the bulb from the rear, a practice which largely overcomes the difficulty of reflector deterioration.

The provision of a satisfactory open-road beam is not a difficult problem ; it is a matter of determining what light distribution is required for adequate seeing distances and, provided the motorist is prepared to fit the necessary equipment, any reasonable requirement can be met. With the dipped beam, however, questions of principle arise which are best illustrated by a comparison of the two schools of headlighting practice—the Anglo-American and the Continental. The Anglo-American meeting beam is designed to provide the greatest possible seeing distance, bearing in mind the need for reducing glare as much as possible : Continental practice is to provide a meeting beam with as little glare as possible, bearing in mind the need for seeing as far as possible.

Practically all inventors follow this latter principle and the Road Research Laboratory is frequently approached by people who think they have at last solved the headlamp problem (usually on straight roads only) by eliminating in some way or other the light which may fall into an approaching driver's eyes. Such innovations are often based on the use of grills placed in front of the headlamp to prevent rays of light being sent upwards, or to the offside, or sometimes in all directions except straight ahead. Other inventors suggest placing headlamps inside the car so that they will be screened by the bodywork, or pointing them sideways, or rearwards or mounting them on top of the vehicle and pointing them downwards. Another group try to achieve the same glare reduction by visors for use by the driver experiencing glare : there are grilled visors, reflecting visors, fixed neutral, variable density neutral and coloured visors : spectacles with similar properties also have their advocates. To all such persons, good headlighting means first and foremost non-glaring headlighting.

A comparison of the method by which the Anglo-American and the Continental meeting beams are produced shows the way in which these conflicting principles lead to different headlamp design.

§ 2. THE ANGLO-AMERICAN LAMP

In the Anglo-American system, typified by a British block lens lamp, transverse filaments are mounted at and above the focus of a parabolic reflector (Fig. 1). When the light from the upper filament and reflector is thrown on to a screen it will produce an oval patch of light. If an opaque disc with a small hole is moved across the face of the reflector it will be seen that this oval patch of light is made up of innumerable images of the filament, in some cases viewed end on, in others viewed sideways. By means of the prisms and flutes which comprise the block lens the lamp designer treats the light from each part of the reflector separately, deflecting unwanted rays downwards or to the side ; the lens is, so to speak, tailored to suit the reflector so that the light is sent where it is required. An example of this type of lens for driving on the left-hand side of the road is shown in Fig. 2. The lamp is aimed with the main beam switched on : the filament producing the dipped beam is offset which ensures that the peak intensity of the meeting beam is directed along the nearside of the road.

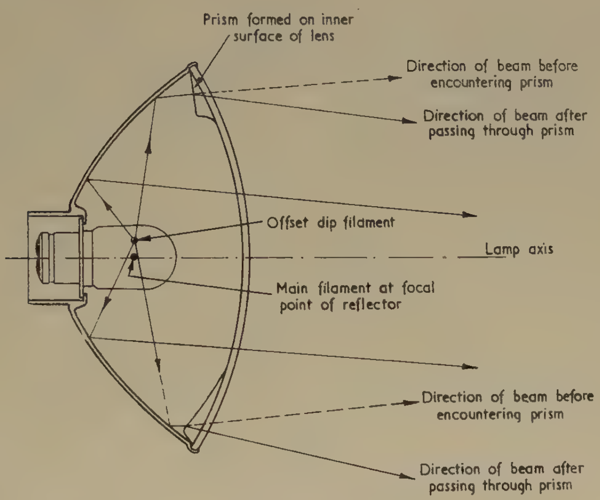

Prism formed on inner surface of lens
Direction of beam before encountering prism
Direction of beam after passing through prism
Offset dip filament
Lamp axis
Main filament at focal point of reflector
Direction of beam before encountering prism
Direction of beam after passing through prism

Figure 1. Anglo-American Optical System.

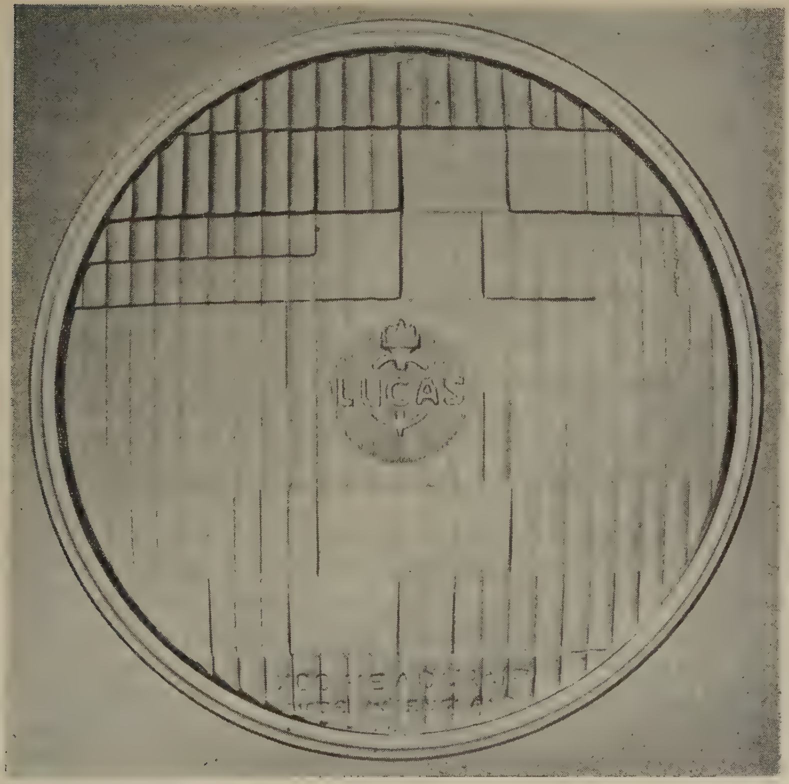


Figure 2. Headlight lens for left-hand side of road.

The beam distribution of such a lamp, that is, a diagram which gives contours of equal apparent intensity, is shown in Fig. 3. It will be noticed that the beam is asymmetric and, as the close spacing of the contours indicates, that there is a fairly rapid transition from high to low intensity, but in spite of this there is appreciable glare. The glaring intensity from two lamps at the eyes of an approaching driver 250 feet away on the opposite side of a 20-foot carriageway is about 1400 candelas. The intensity directed towards the top of an object eighteen inches high straight in front of the vehicle also 250 feet ahead is 3100 candelas, both of which intensities will be compared later with those of the Continental system.

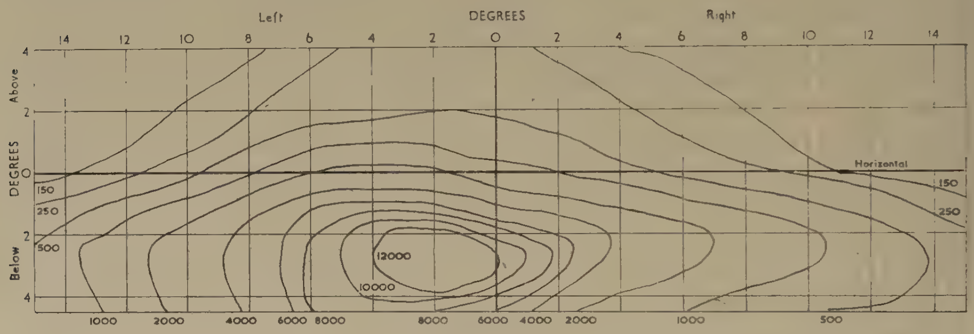


Figure 3. The meeting-beam distribution from one modern British lamp.

§ 3. The Continental Type Lamp

The Continental lamp, in use in Germany as the Osram Bilux system and in Holland as the Philips Duplo system, is based on a special bulb designed in 1920 by Graves and marketed in Great Britain as the Lucas-Graves system (Nelson 1954–55). In this lamp a parabolic reflector is fitted with a bulb with an axial filament, the rear end of which is at focus of the reflector. When the light from such an arrangement is directed on to a screen a circular patch of light is produced. If the surface of the reflector is again explored by means of the opaque disc with a hole, it will be found that in this case the circular patch is made up of a series of images of the filament radiating from its centre. Furthermore, the images which are likely to cause glare, namely those which lie in the top half of the patch, all come from the bottom half of the reflector. If this is completely covered up a semicircular image is produced with a very sharp transition from light to dark at the top edge ; such an arrangement is said to have a sharp cut-off.

In practice in the Continental lamp the reflector is not covered, instead (Fig. 4) a small hood below the ' dip ' filament is used to intercept the light before it reaches the reflector. An appreciable amount of light is wasted by doing this but a sharp cut-off is obtained, as will be apparent from Fig. 5, which shows a typical beam distribution of such a lamp when fitted with a lens to spread the light symmetrically to right and left. The glare to the driver 250 feet away from two such lamps is about 600 candelas, much less than that obtained for the British lamps, but the intensity directed towards an object 250 feet away is only about 1100 candelas. In this case, therefore, there is less glare but also less light available for seeing than in the case of the

Anglo-American type of lamp. How do these differences affect the seeing distance of a driver ? This question can only be answered by experiment and some investigations on this subject are outlined below.

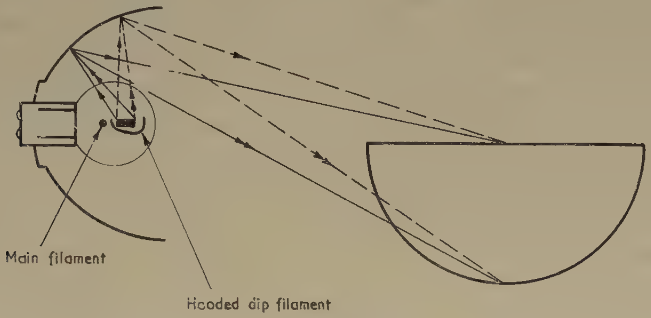
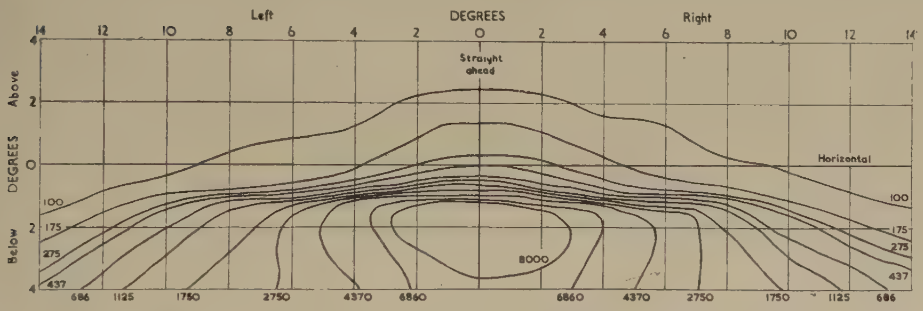


Figure 4. Formation of the dipped beam in the Continental lamp.



Figures to curves denote beam intensity in candelas

Figure 5. Dipped-beam distribution from one Continental lamp.

§ 4. THE DETERMINATION OF SEEING DISTANCES

Seeing distances have been measured at the Road Research Laboratory (Grime 1954–55, Harris 1954) by a simplified form of a method originally used by Roper and Howard (1938) in America. One car remains stationary to provide a glare source and another car which is driven towards the stationary car, carries the observer. A test object 18 inches high with a reflection factor of 7 per cent (equivalent to a medium grey suiting) is placed 10 feet behind the stationary lamps as shown in Fig. 6. This is almost the most difficult place at which to detect an object and the test therefore gives a distance nearly equal to the minimum obtained in more elaborate experiments where a range of object positions is used. The tests were further simplified by using headlamps which produced beams of uniform intensity so that neither the intensity directed to the test object nor that directed to the observer's eyes varied during the test run. This ensured that conditions from one test to another were reproducible although they were not of course exactly similar to road conditions. Nevertheless, the results were in agreement with conventional seeing-distance measurements.

The results obtained from a large number of tests are given in Fig. 7. It should be remembered that these results apply to a particular observer and to a small object lighter than the darkest clothing, which has a reflection factor of only 2 per cent. The basic data can however be generalized and used to compare various headlamp systems if several reasonable assumptions are accepted. The first of these is that although the seeing distances obtained by a particular observer may differ from those of another in absolute magnitude, results obtained by this observer for different systems would be ranked in the same order by other observers. No evidence has so far been found to disprove this assumption.

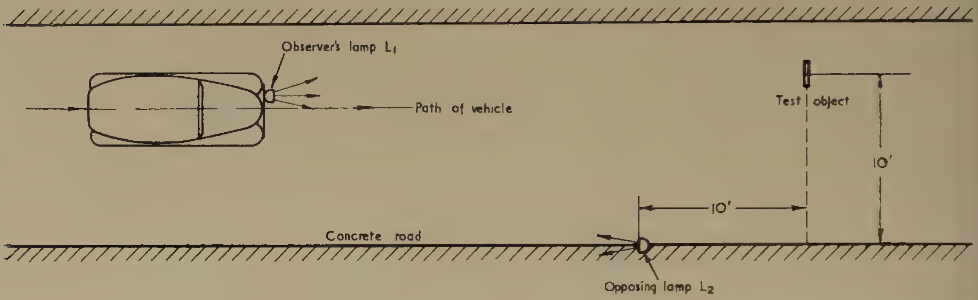


Figure 6. Layout of visibility test.

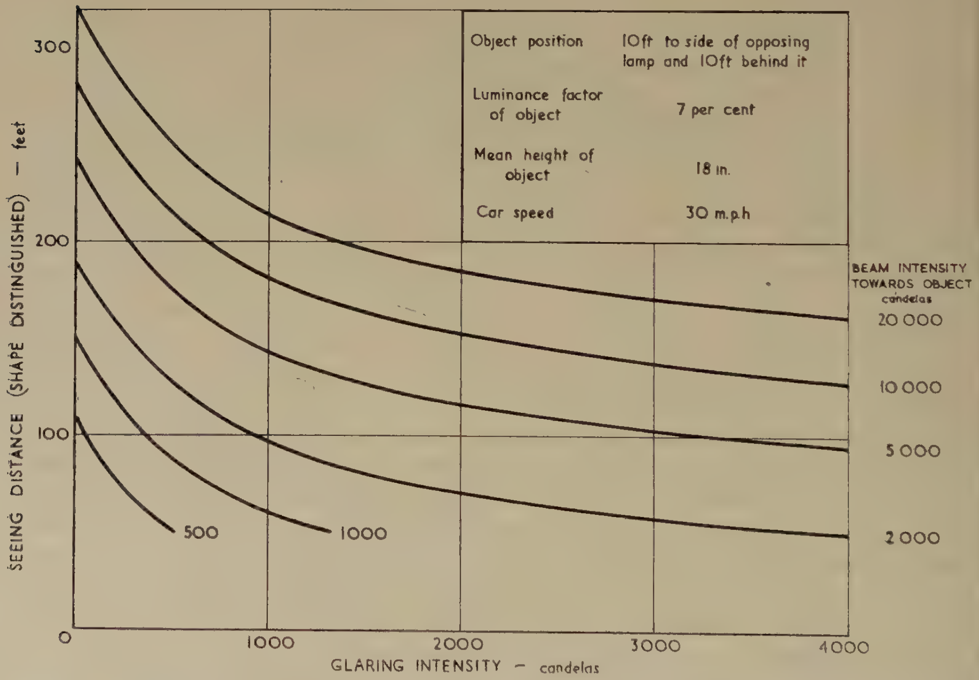


Figure 7. The relation between seeing distance, beam intensity directed at an object and glaring intensity.

The second assumption is concerned with the effect of glaring light on visual discrimination. It is generally agreed that a glare source has the same effect on the eye as if uniform illumination were to be spread over both the object being searched for and its background; that is, the contrast ratio between object and background is lowered. It is thought that this effect is chiefly due to the scattering of light in the media of the eye between cornea and retina and a measure of the effect is given by the empirical Stiles (1929) Holladay (1926) relationship. This states that two glare sources have the same effect if E/θ^2 is the same for both, where E is the illumination at the eyes due to the glare source, and θ is the angular separation in the field of view between the object looked at and the source of glare.

Starting therefore with the basic data of Fig. 7, it is possible using this relationship to determine the seeing distances which would be obtained for other values of intensity directed towards the object, other glare intensities and other object positions. In fact, as Jehu (1955) has shown from the geometry of the system, together with a beam distribution for any headlamp arrangement, it is possible to calculate seeing-distance curves, and hence compare headlamp systems. The results of such calculations for examples of correctly aimed headlamps of the type described previously are shown in Figs. 8 and 9. Four object positions on a 20-foot road have been considered: an object 2 feet from the nearside kerb (nearside object), a straight-ahead object, an object in the centre of the road and an object 2 feet from the offside kerb.

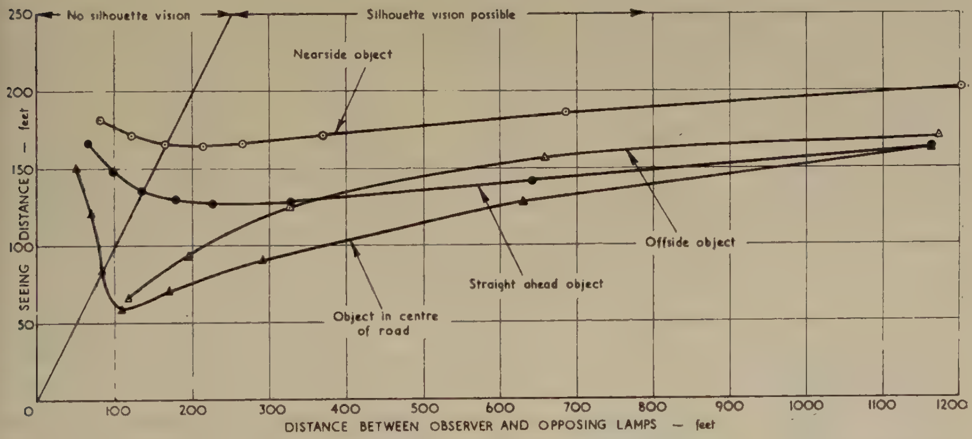


Figure 8. Direct seeing-distance curves for objects on a 20 ft. road with the double-lamp British meeting beam.

It will be seen that the Continental dipped beam, although it at all times produces less glare than the British dipped beam, gives poorer seeing along the nearside of the road where cyclists and pedestrians might be expected.

In the example given, when the object is straight ahead and the two vehicles are 250 feet apart, correctly aimed Continental headlamps enable the standard object to be seen at 125 feet; correctly aimed British lamps enable it to be seen at 127 feet. The extra glare produced by the British lamps is compensated for by the extra light on the object. It will be noticed that the ratio of glare to illumination on the object, is roughly the same for both types of lamp and it is this ratio which primarily determines seeing distance. Furthermore, subjective estimates of dazzle, which may be defined as the unpleasant sensation produced by glare, suggest that dazzle also depends on this glare/illumination ratio rather than on glare itself. For example, a headlight switched on to the upper beam in daylight is not regarded as dazzling, although it is producing just as much glare as at night, because the glare/illumination of the surroundings, ratio is so very much less than at night.

It would be more logical to concentrate on reduction of dazzle rather than of glare. The reason Continental manufacturers have not done this is probably because measurement would have to be subjective and subjective measurements are notoriously difficult. By relying on a performance test, such as obtaining maximum seeing distance, the Anglo-American school have reduced the disabling effects of dazzle to a level equal to, or lower than that of the Continental manufacturers. For an object in the centre of the road, the seeing distance of the Continental lamp is better.

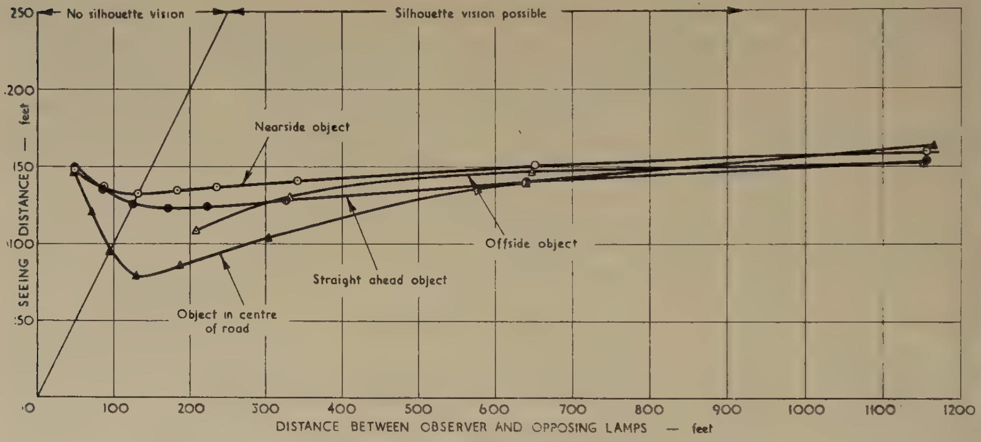


Figure 9. Direct seeing distance curves for objects on a 20 ft. road with the double-lamp Continental meeting beam.

These comparisons are correct for correctly aimed beams. However, the majority of headlamp beams are not correctly aimed : in a check carried out in Oxfordshire in 1952 half the cars examined had lamps pointing 2° or more from the correct position. The Continental beam is very susceptible to misaim as owing to the rapid change in intensity from top to bottom of the beam quite a small upward tilt can cause severe glare. For places where misaim is the rule rather than the exception there is much to be said for the Anglo-American system.

There has recently been a change in design of Continental lamps (de Boer 1955 a, b), for it was announced after a meeting of the International Standards Organisation in June 1956 that European manufacturers were to make a new lamp with what is called the ' unified European beam '. The new beam is asymmetric, with a sharp cut-off produced in the same way as in the old beam, but by shaping the metal shield the cut-off is lifted at the nearside, throwing a more powerful beam of light along the edge of the road. An example of the type of beam produced is shown in Fig. 10.

Full tests have not yet been made on this lamp but it appears likely that its performance will be similar to that of the new American lamps provided the necessary accuracy of aim is achieved.

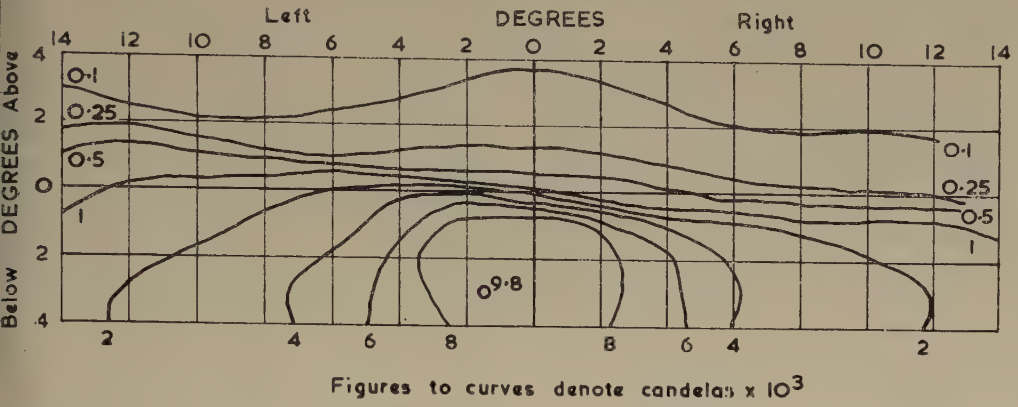


Figure 10. An example of the light distribution of the new unified European beam (mid 1956).

§ 5. Subjective Comparisons of Headlamps

Measurements and calculations of seeing distance give very little indication whether the beam gives the driver confidence in his ability to place the vehicle on the road, and to judge this quality in the beam, road tests are often advocated. The usual way of carrying out such tests is to use the lamp on the public roads and to assess its merits subjectively. The most serious objection to this method of test is that it is not fair to judge a lamp, except when it is meeting a similar lamp, which is not possible on public roads. Another objection is that it is very difficult to remember what one headlamp system is like compared with another unless the change-over is made very quickly.

A method of subjective assessment which overcomes these difficulties has been described by Grime (1954). These tests were carried out using two similar vehicles on a track half a mile long with a curve at each end. Large obstacles of wood and hessian were set up at the edges of the track and smaller obstacles were set up in the middle. It was just possible by steering a straight course to meet and pass an oncoming vehicle without touching vehicle or obstacles. Each vehicle was fitted with the two types of headlamp system A and B to be compared and the procedure was for each person to make 8 runs, 4 as observer, 4 as driver, using the lamps in the order ABBA, ABBA; thus lamp A was always opposed to lamp A, and B to lamp B, in such a way as to reduce systematic error. After the 8 runs each driver completed a questionnaire and noted his preferences. Tests were run with the roads dry, and after wetting by a water-spraying tanker.

In a comparison by this method of the British and Continental systems it was found that the British was preferred in almost all trials particularly on wet roads, where the symmetrical Continental beam produced very bright reflections on the road surface. When using the Continental beam, the ' flashing ' of the sharp cut-off beam due to the pitching of the oncoming vehicle was found to be disturbing.

These tests showed the importance of having plenty of light close to the vehicle so that the kerbs and grass verges could be readily seen. This spreading of the beam sideways is a feature of modern headlamp practice and is one reason why they are more comfortable to drive with than pre-war lamps.

§ 6. PRESENT CONDITIONS IN GREAT BRITAIN

Up to the present, discussion has been confined to what is possible with modern headlamps properly adjusted. On the roads of Great Britain these conditions are not realized. There is no legal requirement for a driver to use headlamps at all; he could use oil lamps or candles, or alternatively even a searchlight. No one is very likely to stop him if his lights point to the sky or at the oncoming driver's eyes. The result of this is that, instead of uniform seeing conditions when meeting other vehicles, sometimes extremely glaring lights are met which reduce one's own seeing distance; at other times the oncoming driver's lamps are so poor that he must suffer dazzle even from correctly aimed lamps.

From the survey of headlamp aim referred to previously it is estimated that one-quarter of the drivers would not be able to detect the test object at 75 feet in more than half their encounters with other vehicles. About 5 per cent would see no further than 50 feet in half their encounters.

A very substantial improvement in visibility and dazzle is possible if means could be found to improve aim, and restore or replace deteriorated bulbs, reflectors and lenses. This improvement would be far more spectacular than the changing of lamp design, which is neither necessary nor desirable under present conditions.

§ 7. THE FUTURE

It was mentioned earlier that there were two conflicting requirements for a good headlamp, the flooding of the road with light and yet the prevention of it from reaching an oncoming driver's eyes. A complete solution of this problem is not possible with ordinary light but by polarizing the light from headlamps, a system is possible which, at first sight, offers a complete answer to the difficulties.

The principle involved depends upon a property of electromagnetic waves, of which ordinary rays of light are an example. These waves consist of an electric vibration at right angles to the direction of motion of the rays. In a ray of ordinary light this electric vibration has no special direction; over a short period of time it is just as likely to be up and down as left to right. However, by passing the ray of light through a device called a polarizer the emergent light ray will be found to vibrate in one direction only which can be changed by turning the polarizer; light vibrating in other directions has been absorbed. The light reflected from a polished surface, for example, the top of a desk, is partly polarized, the electric vibrations lying parallel to the reflecting surface. The waves of much greater wavelength from television transmitters are polarized usually up and down, which is why television aerials have vertical rods; on the other hand, in England, high-fidelity radio waves are horizontally polarized and hence aerials for their reception have horizontal rods.

If a ray of light which has been polarized as described, is passed through another polarizer oriented in exactly the same way, the light will be passed through. If, however, the second polarizer is oriented at right angles the light will be stopped.

The way in which this property of light can be used to provide glareless headlighting is shown in Fig. 11. By polarizing the light from one's own headlamps at an angle of 45° to the horizontal, it is possible by looking through a visor oriented at the same angle, for light from one's own lamps on returning from the road, hedges, kerbs, etc. to reach the eye. On the other hand, light from an oncoming driver's lamps will be completely cut off by the visor, which will be seen from Fig. 11 to be arranged at 90° to oncoming lamps. The theory and possibilities of such a system have been dealt with by Jehu (1956 a, b, c) who has shown that, using available polarizing materials, the amount of glare light can be reduced to less than a two-hundredth of its original value.

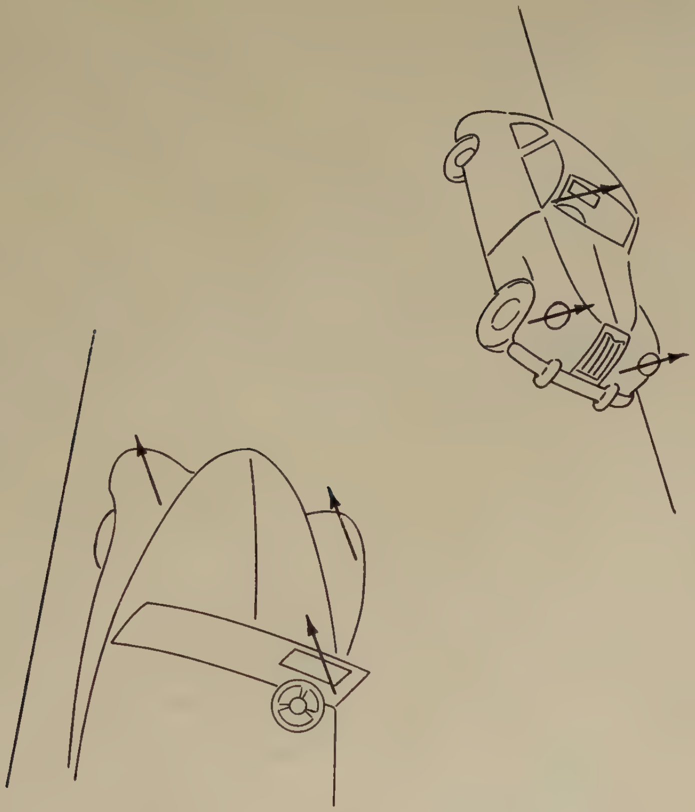


Figure 11. The polarized headlight system.

In Fig. 12 a comparison is made between seeing distances with a polarized system and with a conventional system. It will be seen that using undipped polarized headlamps and viewing visors, much greater seeing distances can be obtained than with the normal dipped system. In practice all that can be seen of the opposing vehicle's lamps is a blue glow instead of the normal white glare. Objects near the vehicle and the vehicle itself can be clearly seen.

There are numerous disadvantages of the system however. First, it is expensive for the following reasons. Suppose a single pair of headlamps is used for both main and meeting beams. It is found that the main open-road beam is seriously reduced in effective intensity by the light losses in polarizer and analyser and by depolarization of light from the headlamps when reflected by the road surface. These losses are not due to inferior materials but to the physical processes involved. Because of these losses it is necessary to use lamps of roughly five times the wattage of normal lamps to obtain seeing conditions on the open road equal to those of ordinary lamps. This means special bulbs and lamps, heavier wiring, and a larger generator.

An alternative is to use four headlamps; two unpolarized lamps for open-road driving, two polarized lamps for the meeting beam. This would be in line with coming fashion as there is already a move in America to fit four headlamps on the more expensive cars, but either solution would increase the cost of vehicle lighting.

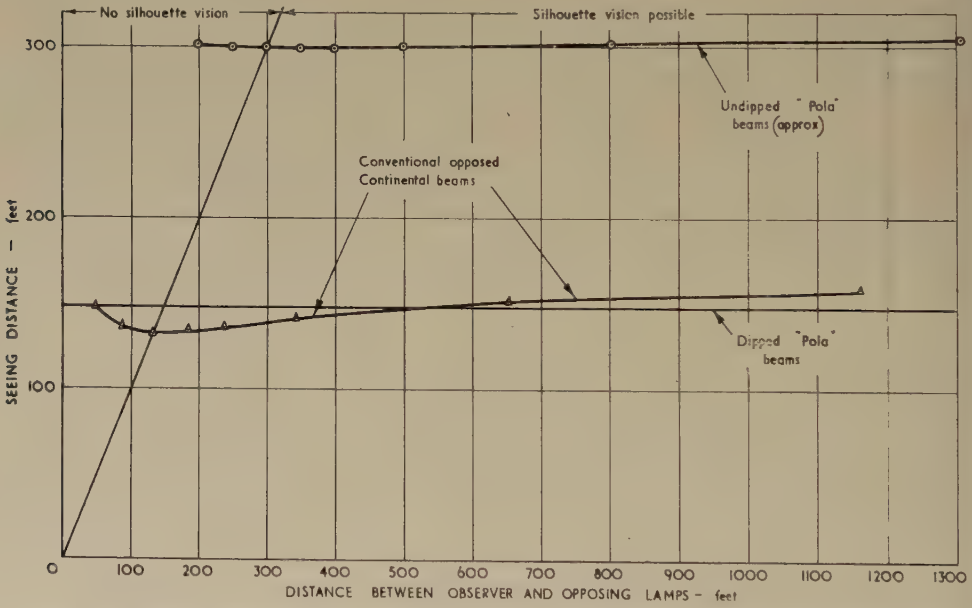


Figure 12. Seeing distances for a nearside object with conventional and polarized meeting beams.

A third alternative, which is being tested at the Road Research Laboratory is to use a lamp giving a partly polarized beam ; the light emitted in a direction which might cause dazzle is polarized but the light falling on the road near the vehicle is unpolarized. By this means it is hoped to reach a more economical solution.

It is found that in practice there are further disadvantages of polarized light. For example, windscreens manufactured on the Continent and in Great Britain are usually made of toughened glass, which is a double-refracting material and shows strain patterns when viewed in polarized light. To overcome this it is necessary either to replace the windscreen by one of laminated glass such as is used in America, or to fix the visor on the outside of the windscreen where it would have to resist the abrasion of windscreen wipers.

When driving against vehicles fitted with polarized lamps, one has to rely on one's own lamps ; the visual clues one normally obtains of the approach of another vehicle round a bend by the lighting up of the haze disappear. This may be quite a serious loss which has to be weighed against the great advantage of being able to see clearly in all meeting situations.

A polarized beam of course appears just as glaring as an ordinary beam of the same intensity to an unprotected observer and cyclists and other road users would probably find it advisable to wear polarizing spectacles to protect themselves.

As far as is known, no large manufacturer or country is at present seriously thinking of changing over to a polarized headlamp system. If a driver fits such headlamps he does not help himself but other drivers. In America where this matter has been seriously discussed they argue thus :—the man who buys a new car, probably does so once a year. If a polarized light system costs $100 he may have to invest $500, $600 or $700 before his philanthropy is rewarded and most cars he meets are fitted with polarized lighting systems. The encouragement of such far-sightedness is not without its difficulties in other spheres of life and does, at the moment, appear to be a serious difficulty in the vehicle headlighting field.

Ways of overcoming this difficulty of a change-over from ordinary to polarized light appear to offer a fruitful field of investigation.

§ 8. CONCLUSIONS

The main conclusions reached during the course of research are :

(1) A very substantial improvement in visibility and dazzle is possible with equipment now on the road if means can be found to improve aim and restore or replace damaged lamps.

(2) No great improvement is possible by a change of lamp design using ordinary light.

(3) The most hopeful field of enquiry is the use of a polarized headlamp system.

This paper is published by permission of the Director of Road Research.

On passe en revue succincte le développement des phares de voitures. On décrit les principes de la construction du phare à lentille à blocs, employée en Amérique et en Grande-Bretagne, et ceux de la construction de la lentille à constraste marqué, employée dans les pays de l'Europe continentale, et l'on compare les deux systèmes.

On décrit le système du phare à polarisation, qui est étudié à présent au Laboratoire.

Es wird ein kurzer Überblick der geschichtlichen Entwicklung der Kraftwagenscheinwerfer gegeben. Es werden die Grundgedanken der Konstruktion des in Amerika und Grossbritannien angewandten BlocklinsenScheinwerfers, sowie der auf dem Kontinent Europas üblichen Scharfkontrastlinse beschrieben, worauf beide Systeme miteinander verglichen werden.

Man beschreibt das gegenwärtig im Laboratorium untersuchte Polarisationsscheinwerfersystem.

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SIMPLIFYING THE OPERATOR'S TASK AS A CONTROLLER

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As a method of task simplification, ' quickening ' has been applied to a number of continuous control problems with encouraging results. In the studies reported here the employment of this technique resulted in substantially increased pilot–helicopter stability while concomitantly reducing the pilot's required physical output. It is felt that these dual advantages should do much toward alleviating the fatigue problem in helicopter instrument flight.

§ 1.

One of the effects of technological advance has been the transfer to the machine of many routine tasks formerly assigned to the operator. However, in many cases its effect has been to increase the demands imposed upon man in those areas where he continues to play an important role. These areas primarily involve decision-making and controlling functions. The operator now is forced to make increasingly complex decisions within shorter time limits or to control system performance to higher levels of precision than ever before. In many instances he is responsible for both functions. In such situations it seems reasonable that, to the extent that we can simplify the operator's role as a controller, his decision-making role may be enhanced.

One of the approaches of our laboratory to the problem of control task simplification is through the technique of display ' quickening ' (Birmingham and Taylor 1954). To describe this technique we might begin by considering some situations in which it appears to be particularly applicable. When an operator must respond to an instrument indication of performance to steer a ship, control a submarine, or pilot an aircraft, he finds that there is a remote and complex relationship between his control motions and the response of the vehicle. Such response lags stem primarily from the system dynamics and the medium in which the vehicle operates.

To function as an effective continuous control device in such systems requires an unusually high degree of skill. The operator must evolve a complex pattern of predictive behaviour to compensate for the delays inherent in the system. It is the specific purpose of ' quickening ' to eliminate the necessity for this difficult mental computation by designing it into the system itself. This is accomplished by providing feedback information, similar in many respects to that provided in automatic systems designed to perform the same task. Derivative terms are added to the displayed output which the operator is trying to control and presented as a single indication of error. The effect is to provide the man with immediate knowledge of the effects of his own control motions.

The helicopter provides an excellent test of this approach to control problems. Because of its performance characteristics, it is uniquely suited to many tasks in which other vehicles would have limited value. Unfortunately, it has not been possible to exploit this potential fully. As currently designed, the helicopter can be used effectively only under conditions of good visual contact with the ground. All-weather flight has been infeasible not only because of its basic instability but also because of the nature of the information available to the pilot for controlling its flight path. Helicopter flight instruments have been largely inherited from the more stable fixed-wing aircraft and are entirely inadequate for slow flight and hovering. Even with ideal weather conditions, hovering imposes an unusually high work load on the pilot. His hands and feet are in constant motion as he attempts to provide stability to a basically unstable vehicle. The addition of the increased tension and strain of instrument flight to this work load poses a serious problem.

§ 2. Preliminary Helicopter Study

The utility of applying the display quickening technique to helicopter instrumentation was investigated in an exploratory study (Bailey and Sweeney 1955). The hovering equation for pitch only was simulated on an analogue computer and the operator's task was to stabilize pitch attitude while subject to simulated gust disturbances. Two derivative feedback configurations were used and compared with the performance achieved with a standard gyro-horizon type display. Figure 1 presents some sample recordings from this preliminary study.

The upper tracing shows one of the gust patterns used and the paired tracings below indicate the changes in helicopter attitude and the operator's control motions for each test condition. The first pair of tracings were obtained with the gyro-horizon display, while the other pairs represent the

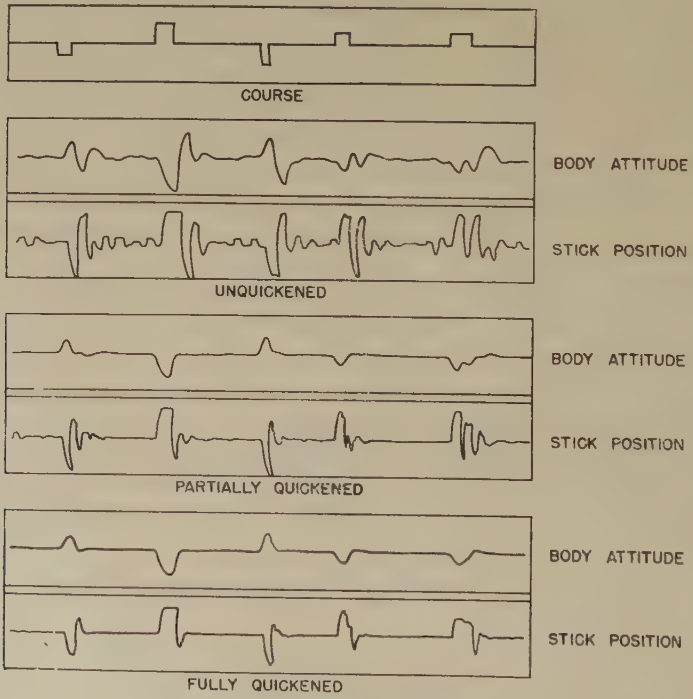

Figure 1. Simulated helicopter recovery from gust-disturbances while hovering. Pitch only.

two different quickening configurations. It can be seen that both derivative feedback displays resulted in a much more stable pilot–helicopter combination as indicated by the fuselage attitude tracings. An important concomitant of this increased stability was the pronounced reduction in the operator's physical output as measured by control stick motion. Inappropriate motions were, to a great extent, eliminated.

Of, course, attitude stability alone will not assure effective hovering performance. To hover with the requisite degree of precision in adverse weather conditions, the pilot must have knowledge of both longitudinal and lateral motion along the ground. Since this groundspeed information is even further removed from his control input than vehicle attitude, it was felt that hovering precision would be markedly influenced by the manner in which this information was processed and presented to the pilot.

§ 2. A Second Study

In a second study (Sweeney *et al.* 1954) a ' conventional ', an ' integrated ', and a ' quickened ' display system were evaluated to determine their relative contribution to hovering accuracy. To investigate this problem the longitudinal, lateral, and heading equations of motion for a helicopter were simulated on an analogue computer and the controls and displays incorporated in a cockpit set-up.

With the conventional display system, groundspeed was presented as a separate item of information on the upper portion of the instrument panel and the artificial horizon at the lower right (Fig. 2). This arrangement represents the traditional solution to the problem of presenting new information to the pilot by adding a separate meter, light, or dial to the array of instruments already present in the cockpit.

The groundspeed display indicated the longitudinal rate of motion by a vertical displacement of the dot and lateral ground rate by left–right motion of the dot. With this condition, the operator had to learn the dynamic relationship between his control, the attitude display, and groundspeed, as well as a scanning process appropriate to the task.

For integrated display condition, attitude information was simply transferred to the groundspeed indicator, providing a combined display.

In the quickened system, control stick position, helicopter attitude, and attitude rate for both the lateral and longitudinal coordinates, were summed to the groundspeed signal in a single display indication, and the attitude reference line was removed.

In order to examine the relative susceptibility of each display system to the stress of a secondary task, the control of heading was imposed on the three primary conditions.

During the training and experimental phases of this study each subject accumulated almost 25 hours of simulator time. The results are summarized in Fig. 3. The unshaded bars represent error obtained with each of the three primary conditions when the operator attempted to counter the gusts. The shaded bars indicate the error in hovering performance which occurred when the operator had the additional task of controlling heading. The heading error scores themselves are not presented, but no significant differences were found. Utilizing as the criteria of hovering accuracy the minimization of

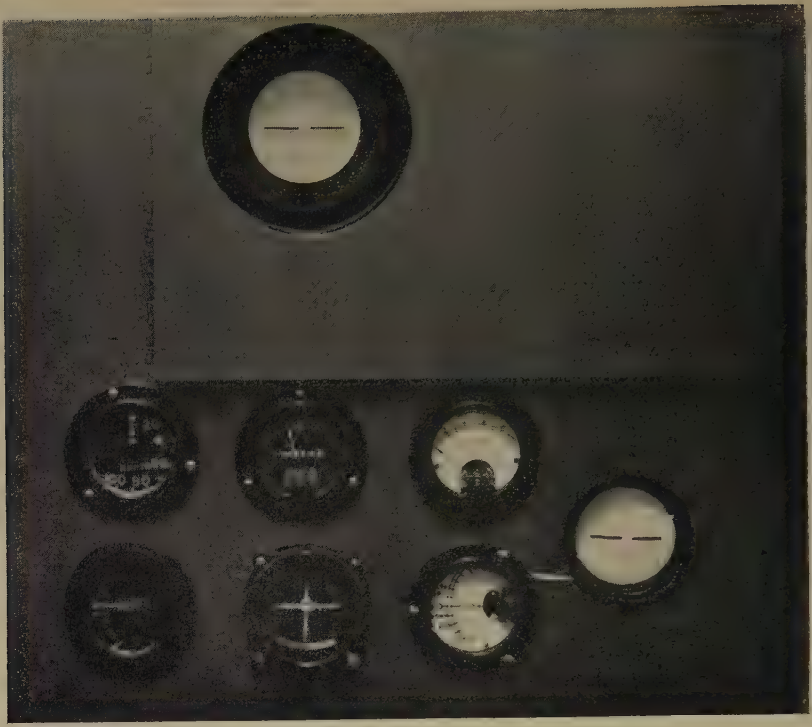

Figure 2. Helicopter simulator instrument panel.

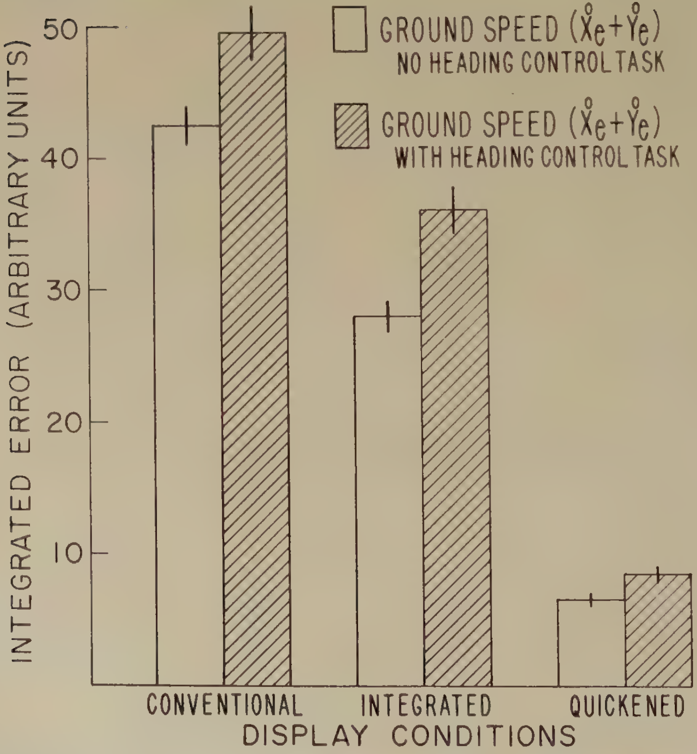

Figure 3. Groundspeed error for each test condition. Average for 6 subjects.

lateral and longitudinal motion, the results indicate that the quickened system was six times more effective than the conventional system and four times as effective as the integrated system. While the secondary task adversely affected hovering performance on all systems, the ratio of effectiveness was essentially unchanged.

It should be emphasized that since all other system parameters were held constant, these results must stem from differences in the nature of the task as structured by each display system.

Clearly, the degree of task simplification achieved with quickening substantially increased pilot–helicopter stability while reducing his required physical output. The application of the technique should do much to alleviate the fatigue problem in helicopter instrument flight.

Quickening has been applied to a number of control problems with equally encouraging results. It is felt that this approach of integrating and simplifying the operator's task can make some notable contributions in a period of increasing systems complexity.

L'' accélération ' (' quickening ') a été employée avec de bons résultats comme méthode de simplification du travail pour plusieurs problèmes de commande continue. Dans les études décrites dans l'article en question, l'emploi de cette technique a augmenté d'une manière considérable la stabilité ' pilote–hélicoptère ', en réduisant en même temps le rendement physique exigé du pilote. L'auteur est d'avis que ces deux avantages devraient contribuer grandement au problème de la fatigue pendant le vol en hélicoptère à l'aide d'instruments.

Das ' Beschleunigen ' (' quickening ') wurde als Verfahren zur Arbeitsvereinfachung in mehreren Problemen der ununterbrochenen Steuerung mit vielversprechenden Resultaten angewandt. In den hier berichteten Untersuchungen hat die Anwendung dieser Technik eine weitgehende Steigerung der Pilot–Helikopter-Stabilität bewirkt, wobei gleichzeitig die von dem Piloten verlangte physikalische Leistung verringert wird. Der Verfasser ist der Ansicht, dass diese zwei Vorteile zur Erleichterung des Ermüdungsproblems im Helikopter-Instrumentenflug weitgehend beitragen dürfte.

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THE RELATIONSHIP BETWEEN DIAL SIZE, READING DISTANCE AND READING ACCURACY

By K. F. H. Murrell*,
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The experiment reported suggests that the accuracy of reading a graduated scale is related to the angle subtended at the eye by the called space. There is a critical point representing about 98 per cent accuracy (for all intervals interpolated into five or less parts) below which there is a rapid fall off in accuracy and above which little improvement can be expected. Each combination of scale interval and called interval has a different critical point and from these it is possible to calculate the optimum reading distance for any dial size and *vice versa*. It is possible also to decide which of several alternative graduation systems is likely to be the best.

It was found that 'practised subjects'—who had made more than 2000 readings on a particular graduation system—were able to read a dial at double the distance of an 'unpractised subject' both having 6/6 binocular eyesight. For 'practised subjects' with 6/12 binocular eyesight the reading distances were reduced by one fifth.

§ 1. Introduction

In the past it has usually mattered very little how well or how badly dials and pointers were designed because, given enough time, the required information could be obtained from a scale, however it was designed. Under modern conditions this is no longer true. Operators are often called upon to read large numbers of dials and it is often of great importance that information should be obtained from them quickly, accurately and unambiguously.

This is particularly true of dials used in aircraft and it is not surprising that most of the work on dial design should have been done by experimenters connected with aviation such as Loucks (1944), Grether and Williams (1947), Leyzoreck (1949) and Kappauf and Smith (1948, 1950 a, 1950 b). Because of their interest in aviation problems their work was usually carried out at a viewing distance of about 30 in. with dials varying in size from about 1 in. up to about 4 in. The findings of these workers are on the whole very consistent and they have been summarized by Garner and Gebhard (1949) and other writers. Briefly, the major finding is that errors decrease with increasing space between scale marks, very rapidly until an interval of 0·25 in. is reached, then gradually to a minimum at 0·50 in. From this it is concluded that for maximum reading accuracy the width of the space between marks on any scale should fall between these values. Although not specifically stated it must be assumed that these dimensions relate to a reading distance of 30 in.

When designing panels of dials it is usually desirable to make the panels as small as possible and to do this it is necessary to know the optimum dial size for the distance from which the panel is to be read. It seems reasonable to assume that the optimum size of dial for any reading distance would be directly proportional to the distance and on this assumption it can be shown that for reading at 20 ft the optimum dial size for a 200 lb pressure gauge sub-divided into tens would be 20 in. if the calculation is based on the data mentioned above*. This is much larger than is normally found in practice, which suggests that either the assumption or the dimensions are wrong. The present experiment was undertaken in order to obtain further information on the optimum size of dial to be used at different reading distances.

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* Now at the Department of Psychology, University of Bristol.

§ 2. DETAILS OF THE EXPERIMENT

The method used was that developed by Kappauf, Smith and Bray (1947) which consisted in mounting 12 dials on a board and exposing them to the subject who was required to read indicated values at his own pace, timing being made from the end of the first reading to the end of the eleventh reading. For a discussion of the theoretical basis of this method, the report referred to above should be consulted.

Five dial sizes were used, of 2, 3, 4, 6 and 8 in. diameter. These are nominal sizes, being the size of the dial blank as defined in British Standard No. 1780. The actual scale diameters were 5/6th of the dial blank diameter. The scales were black on white and the figures used were those designed by Mackworth (1950). A 200-unit 270° scale, with zero at 3 o'clock, was numbered in twenties and sub-divided into tens. This sub-division was chosen after a preliminary experiment in which scales numbered in twenties sub-divided into fives, numbered in twenties sub-divided into tens, and numbered in fifties sub-divided into tens were compared: it was found that the 20 × 10 scale was read more quickly and just as accurately as the 20 × 5 and more quickly and more accurately than the 50 × 10.

Each set of 12 dials was mounted on a board which could rapidly be placed vertically in a frame. In front of the frame was a buff-coloured blind which could be pulled up by hand to hide the dials. The boards were painted grey with a reflection factor of 60 per cent.; the brightness of the dial faces was 30 foot-lamberts.

The readings to which the pointers were set were obtained from tables of random numbers and were marked on the face of each dial by means of small indentations exactly positioned with the aid of a superimposed finely graduated scale. These marks were clearly visible to the experimenter when illuminated with oblique lighting but could not be seen by the subjects with even lighting and it was thus possible to position the pointers quickly and accurately.

In front of the curtain were positioned six chairs with a point 6 in. forward of the back legs at distances $2\frac{1}{2}$, 6, 9, 12, 18 and 24 ft.

At each session the subject read one board of 12 dials in each size and from each distance, 30 boards in all; each subject did 14 sessions. The order in which the different combinations of dial size and distance were taken by each subject was randomized and was different for each of the six subjects for each of the 14 sessions. It was found that a session lasted about 35 to 40 minutes.

The experimenter displayed the boards one by one, checked the subject's readings against a check list, noted the errors made, and timed the middle ten readings with a stop watch.

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* $0{\cdot}25$ in. $\times 20 = 5$ in. $= \frac{3}{4}$ of the scale circle circumference $= 6{\cdot}66$ in. total scale circumference $= 2{\cdot}12$ in. scale diameter on $2\frac{1}{2}$ in. dial blank (nominal) whence by proportion :

$2\frac{1}{2}$ in. gauge at $2\frac{1}{2}$ ft $=$ 20 in. gauge at 20 ft.

The subjects were instructed to read to the nearest unit as quickly as they could, consistent with accuracy.

The six subjects were Naval Chief Petty Officers. The eyesight of four of them was 6/6 binocular or better, that of the other two was 6/12 binocular. The two latter were included because this standard, without glasses, was accepted in the boiler and engine rooms of Her Majesty's ships. None of the subjects was a stoker and therefore they had not had experience of dial reading in the course of their naval duties.

2.1. *Learning*

In the eight most difficult situations the average number of errors, out of a maximum possible of 12, was 10 for sessions 1 to 4, 8·5 for 5 to 7, 5·3 for 8 to 11, 5·0 for 12 to 14. It will thus be seen that after seven sessions the number of errors was almost halved, after which there was very little improvement. This learning effect showed clearly on some of the smaller dials at the greater distances when after seven sessions or so the subjects stopped saying that they could not read these dials at all and started making readings with some success, though at the greatest distances this did not happen until after ten or more sessions. All the scores, therefore, which were used in the discussion which follows are based on the last seven sessions.

§ 3. DISCUSSION OF RESULTS

Before proceeding to the discussion it is necessary to give some definitions. These are:

Scale spacing *:	The physical size of the interval between two scale marks.
Called spacing:	The physical size of the interval into which the scale space has to be sub-divided 'by eye' (interpolation).
Scale interval *:	The number of units in a scale space.
Called interval:	The number of units in a called space.

In our experiment the scale interval was 10 and it was possible to score the results with various tolerances, such as plus or minus one unit, two units, four units and so on. The tolerance gives us the called interval—thus plus or minus one unit means a called interval of 2 units.

The individual scores for a called interval of 2 units are given in the Table. The individuals have been divided into two groups according to their eyesight. Group A being the subjects with 6/6 eyesight. Subject E appeared to behave differently from the rest: down to the size represented by 2 in. at 9 ft and 4 in. at 18 ft his record conformed to that of the other members of Group A (the scores have been totalled at this point to show this) but beyond this he was worse than Group B. The impression gained by the experimenters was that he was lazy and would not even make an attempt if he thought the task was too difficult, therefore his score has been omitted for sizes smaller than these. It will be noticed that with the very small sizes the subjects did not make the full number of seven attempts. It was decided not to penalize them for this because it appeared that these sizes required even more practice than larger ones, and once a subject started to read a size he continued to read it when it was presented subsequently. Thus the data given for the smallest sizes are based only on the attempts made.

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* These terms are defined in British Standard No. 2643, Glossary of Terms relating to the performance of Measuring Instruments.

Individual Scores in Descending Order of Visual Size for 10×2

Seat distance in feet	Dial diameter in inches	Group A						Group B			
		Errors				Correct		Errors		Correct	
		Subjects E	I	To	S	Total	Per cent	Subjects Tr	Te	Total	Per cent
2½	8	2	0	3	1	330	98·5	2	4	162	96·6
2½	6	0	1	0	1	334	99·5	2	4	162	96·6
2½	4	1	0	1	1	333	99·2	4	3	161	95·9
6	8	0	1	1	1	333	99·2	3	0	165	98·3
2½	3	2	1	2	2	329	98·2	3	2	163	97
6	6	4	0	1	2	329	98·2	3	4	161	95·9
9	8	3/72	0	2	0	319	99·7	2	5	161	95·9
2½	2	2	0	1	2	331	98·7	8	5	155	92·3
6	4	3	1	2	0	330	98·5	7	3	158	94·3
9	6	1	0	0	0	335	99·7	4	2	162	96·6
12	8	2	1	0	2	331	98·7	4	5	159	94·8
6	3	8	0	5	1	322	95·8	12	7	149	88·8
12	6	0/72	2	1	2	319	98·6	7	6	155	92·3
9	4	3	1	4	2	326	97·2	5	6	157	93·4
18	8	1	2	0	2	331	98·7	9	7	152	90·7
6	2	8	3	7	3	315	93·8	9	24	135	80·2
9	3	7	5	5	4	315	93·8	15	13	140	83·2
12	4	11	5	13	2	305	90·9	8	15	145	86·2
18	6	6	3	3	1	324	96·7	7	11	150	89·4
24	8	6	2	11	4	313	93·2	13	16	139	83·7
12	3	16	12	10	4	294	87·4	35	29	104	62
24	6	8	8	12	15	293	87·2	26	29	113	76·3
9	2	28	17	26	17	248	73·8	32/72	37	87	55·8
18	4	15/60	20	20	8	249	79·8	37	27	104	62
Total errors		137	85	130	77			257	264		
per cent errors		6·9	4·2	6·4	3·8			12·9	13·1		
12	2	16/24	39	25	21/72	155	64·6	29/60	31/5	80	50
18	3	—	37/72	25	27/72	139	61·0	50/72	17/2	29	30
24	4	8/12	27	36	38	151	59·5	—	—	0	0
24	3	—	10/24	31	41/72	98	54·4	—	—	0	0
18	2	—	7/12	49	41/60	59	37·8	—	—	0	0
24	2	—	—	33/48	11/12	16	26·7	—	—	0	0
Total errors		161	205	329	256			336	312		

The numbers of errors are those made in 84 readings on each size of dial at each distance. Where less than this number were attempted the number is given, e.g. 15/60.

The Table shows that it is the 'apparent size' of a dial which determines the accuracy with which it is read (for instance a 3 in. dial at 6 ft and a 6 in. at 12 ft are both the same 'apparent size') and after trying various ways of

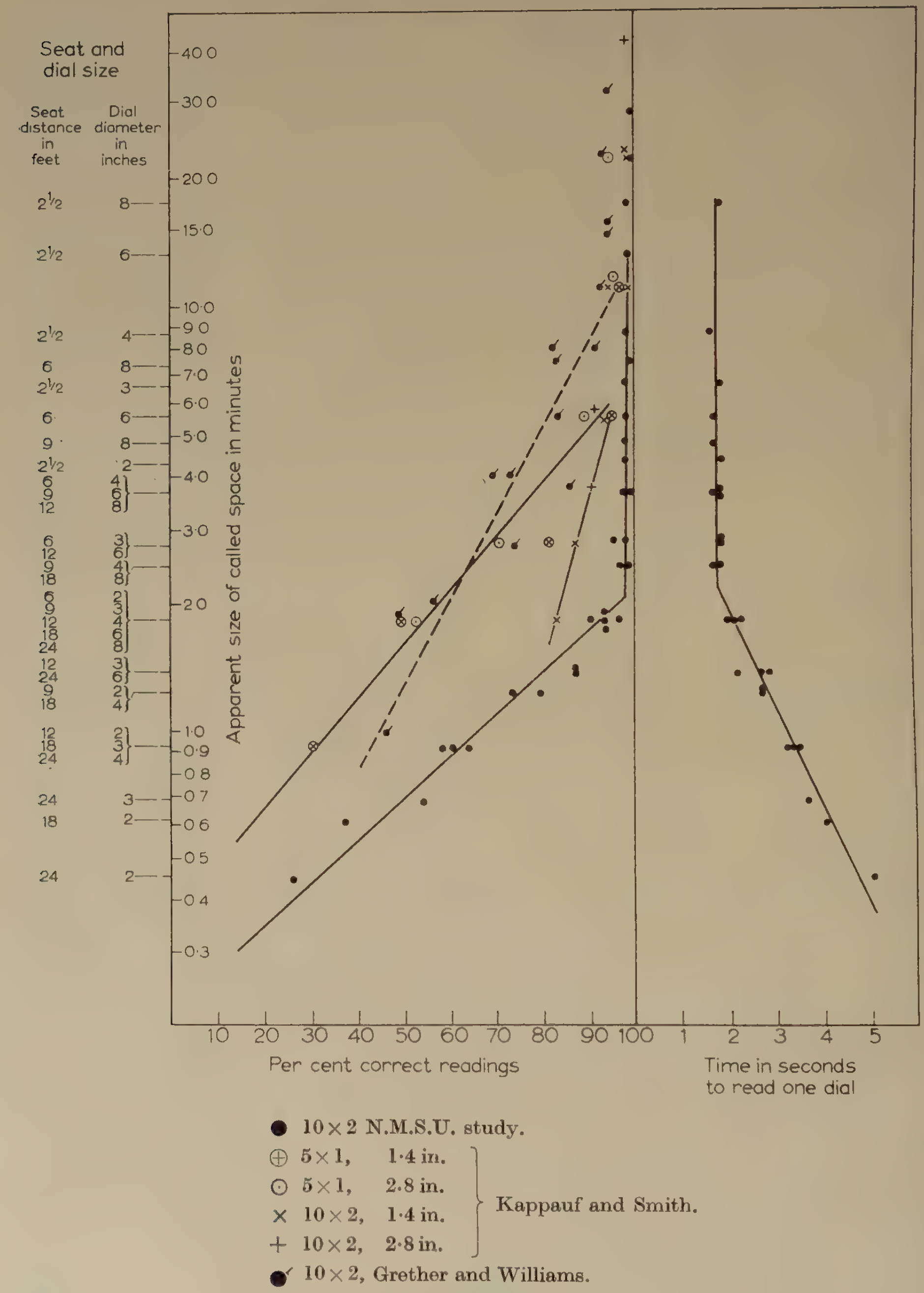

Figure 1.

expressing this it was found that the best presentation was obtained by using the angle (in minutes) subtended at the eye by the called space. The scale space might also have been used but use of the called space enables the results of experiments using different graduation systems—for instance those of Kappauf and Smith (1950 b)—to be reduced to a common unit.

The percentage performance for a called interval of 2 units plotted against log of the angle subtended at the eye by the called space (the 'apparent size') is given in Fig. 1. The reading times are also plotted against apparent size. It will be noticed there is an increase in the percentage of correct readings and a decrease in reading time with increase of apparent size until a critical point is reached, after which there is little or no improvement. Similar curves were constructed for called intervals of 1, 4, 6, 8 and 10. For all these intervals, this critical point was reached at about 98 per cent accuracy except for the called interval of 1 unit when it was reached at 80 per cent.

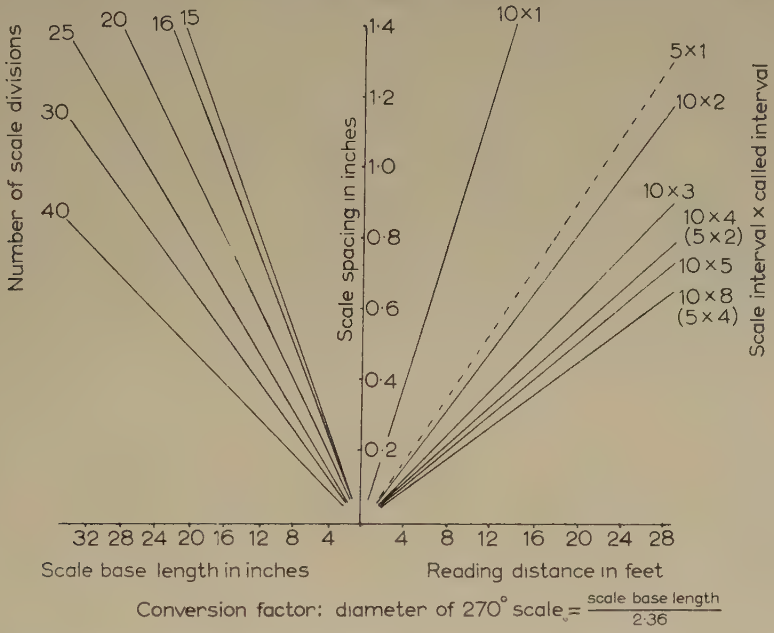

Figure 2. Relationship between reading distance, scale interval, called interval and scale base length (for individuals with eyesight 6/12 or better).

The method of using the nomogram to find the dial size when the maximum reading distance is known can be illustrated by a 200 lb pressure gauge sub-divided into 20 scale divisions at 10 lb intervals, to be read at a distance of 20 ft. Enter the right side of the nomogram at 20 ft and move vertically until the 10 × 2 line is cut, then horizontally to the 20 line and down to the base line to give a scale base length of 17½ in.; to obtain the diameter, divide by 2·36 to give 7·4 in. In practice this means using a standard gauge with a 8 in. dial blank. The nearness of scale base length of 17½ in. at 20 ft reading distance to a 1 : 1 ratio has led the British Standard Institution to suggest the use of a scale base length of 1 in. for each 1 ft reading distance as a useful working relationship.

To obtain the maximum reading distance when the dial size is known the procedure described above is reversed.

It may be noted that should the 200 lb gauge be sub-divided into 40 scale divisions, giving a 5 × 2 interpolation, the scale diameter will be 9·1 instead of 7·4 in. In fact, any method of sub-division other than 10 × 2 gives a less favourable result which suggests that for industrial scales, sub-division into 20 parts and interpolation into 5ths is optimum. Recommended scale graduations and dial sizes based on the above are given by Murrell (1957).

We had available to us two reports, those of Grether and Williams (1947) and Kappauf and Smith (1950 b), which give results in sufficient detail to have enabled us to plot them on the same basis. It will be noticed that Kappauf and Smith's results behave in much the same way as do ours although their curves reach the critical points at higher values of apparent size. This may be due mainly to the greater amount of practice put in by our subjects. Each made more than 2000 readings before scoring started and more than 2000 again during that part of the experiment which was scored. Kappauf and Smith's subjects made in all only 144 readings on each type of dial studied. It seems, therefore, reasonable to conclude that our results represent a performance which could be expected from 'practised observers', whereas the work of Kappauf and Smith represents the performance of 'unpractised observers'. It would seem, moreover, that anyone whose job it is to read dials regularly would very rapidly obtain a proficiency at least equal to that of our practised observers and therefore that our results approximate more closely to normal practice than do those of other workers.

The data for the two subjects with 6/12 eyesight give results similar in form to, but less definite than, those found with subjects with 6/6 eyesight. Equivalent performance appears to have been obtained at a larger apparent size, representing a decrease of reading distance of about one-fifth.

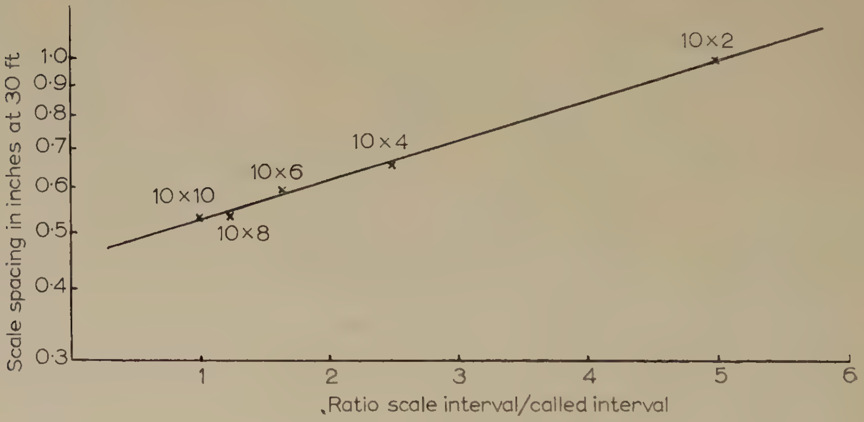

Figure 3. Relationship between scale spacing and interpolation.

The critical point on each of the curves represents the optimum size of the called spacing for a particular interpolation, since smaller called spacings will cause a loss of accuracy whereas larger called spacings will produce little or no improvement. It is quite easy to convert the size of the called spacing represented by each critical point into the corresponding scale spacing. These are shown as a nomogram in Fig. 2 for various reading distances. The left of the nomogram expresses the relationship between scale base length and scale spacing for scales with varying numbers of intervals, and the right-hand side shows the relationship between scale spacing, called interval and reading distance. Thus if the composition of the scale is known the relationship between size and distance can be obtained directly (Murrell 1952).

The slopes of the lines on the right-hand side are related in such a way that if the scale spacing for the various interpolations are calculated for any given reading distance, say 30 ft, and are plotted logarithmically against the scale interval divided by the called interval, the result would appear to be a straight line as shown in Fig. 3.

With the called interval of 1 unit the points representing the viewing distance of $2\frac{1}{2}$ ft did not fall in line with those representing the seats further away. This suggests that when very great accuracy of judgment is required the proportional relationship between size and distance does not hold good for short distances of about 30 in.—the distance at which most American work cited was carried out. This is a matter requiring further investigation.

§ 4. NUMERAL SIZE

We suspected that when our subjects became more practised they read the dials with some success at distances greater than those at which they could read the numerals on the dials. In order to test this point we prepared a series of six cards each with five rows of 10 numerals, each row corresponding to the size of the numerals in each of the five dial sizes. Each subject read one of the cards at each of the six distances and the whole sequence was repeated once. The results are given in Fig. 4 and they confirmed our view. For instance, the numerals of the same size as on the 4 in. dial could not be read at all at 24 ft although at this distance the 4 in. dial was being read to 2 units with 60 per cent accuracy. It is evident that when an observer becomes 'practised' he does not need to be able to read the numerals in order to find his way about.

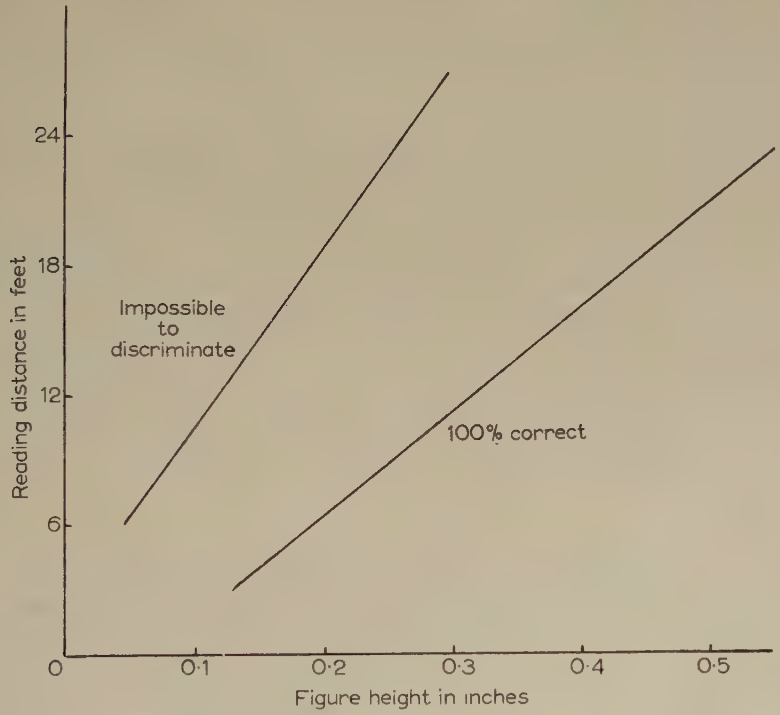

Figure 4. Relationship of numerical height and reading distance.

Figure 4 also establishes a relationship between numeral height and reading distance but this is specific to the Mackworth numerals. Other designs may show greater or less confusion between some numerals but the sizes given by this experiment would seem to indicate the performance to be expected from well-designed numerals.

Thanks are due to the Lords Commissioners of the Admiralty for permission to publish this paper.

L'expérience décrite dans cet article inspire l'idée que l'exactitude de la lecture sur une échelle graduée a un rapport à l'angle sous-tendu à l'œil par l'intervalle ' nommé ' (la dimension physique de l'intervalle qui doit être interpolé ' à l'œil ' entre deux lignes d'une échelle). Il existe un point critique représentant une exactitude d'environ 98 pourcent (pour tous les intervalles interpolés en cinq parties ou moins); au-dessous de ce point il y a un décroissement rapide de l'exactitude, tandis qu'au-dessus de ce point on ne peut s'attendre qu'à une amélioration bien insignifiante. Chaque combinaison de l'intervalle de l'échelle et de l'intervalle ' nommé ' a un point critique individuel ; on peut calculer de ces points critiques la distance optimum de lecture pour toute dimension de cadran et *vice versa.* Il est aussi possible de décider lequel de plusieurs systèmes alternatifs de graduation semble être le meilleur.

On a trouvé que les " sujets avertis "—qui avaient fait plus de 2000 lectures avec un système de graduation donné—pouvaient lire un cadran à une distance deux fois plus grande que le ' sujet non-averti ', quand tous les deux avaient une vue binoculaire de 6/6. Pour les ' sujets avertis ' ayant une vue binoculaire de 6/12 les distances de lecture étaient réduites de 1/5.

Das beschriebene Experiment legt nahe, dass die Ablesegenauigkeit einer graduierten Skala mit dem am Auge von dem ' genannten Intervall ' (physikalische Dimension des Intervalls, welches ' vom Auge ' zwischen zwei Graduierungslinien interpoliert werden soll) unterspannten Winkel nahe verküpft ist. Es existiert ein kritischer Punkt, der ungefähr eine 98 prozent Genauigkeit darstellt (für alle in fünf oder weniger Teile interpolierten Intervalle) ; unterhalb dieses Punktes findet eine steile Genauigkeitsverminderung statt, und oberhalb des Punktes kann beträchtliche Verbesserung kaum erwartet werden. Jede Kombination des Skalenintervalls mit dem ' genannten Intervall ' hat einen besonderen kritischen Punkt ; es ist möglich, aus diesen Punkten die optimale Ableseentfernung für jede Skalenscheibengrösse zu berechnen, und umgekehrt. Es ist ebenfalls möglich zu entscheiden, welches der mehreren alternativen Einteilungssysteme wahrscheinlich das beste ist.

Es wurde gefunden, dass ' geübte Subjekte ', welche mehr als 2000 Ablesungen mit einem gegebenen Einteilungssystem durchgemacht hatten, in zweimal so grosser Entfernung abzulesen vermochten als der ' ungeübte Subjekt ', wobei beide ein Binokularsehvermögen von 6/6 hatten. Für ' geübte Subjekte ' mit einem Binokularsehvermögen von 6/12 vermindern sich die Ableseentfernungen um 1/5.

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LETTER TO THE EDITOR

Dear Sir,

In order to facilitate the exchange of information the Psychology Branch of the Aero Medical Laboratory is interested in discovering all individuals and organizations, both private and governmental, who are engaged or interested in human engineering work. Such people are requested to send their name, the organization involved, its address, and particular areas of specialization or interest to the Psychology Branch, Aero Medical Laboratory, Directorate of Laboratories, Wright Air Development Center, Wright-Patterson Air Force Base, Ohio, U.S.A., Attention : F. H. Rohles. A list of these individuals and organizations will be compiled, and copies will be sent to each participant.

Very truly yours,
FREDERICK H. ROHLES, Jr.,
Major, USAF (MSC).

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Wright Air Development Center,
Air Research and Development Command,
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SUMMARIES OF PAPERS PUBLISHED ELSEWHERE

Authors of papers of ergonomic interest which have been published in other journals or which are available as privately circulated reports are invited to submit summaries for publication in this Journal. They may be sent to any member of the Editorial Board and should be accompanied by a copy of the full paper which will be returned to the author on request.

Holding, D. H. (1957), The effect of initial pointer position on display-control relationships. *Occupational Psychology*, **31,** 126–130.

The paper describes an experiment on a new variable in display-control relationships and shows that the position from which a display indicator begins its travel has an effect on the direction in which the control is moved by an operator unfamiliar with the equipment.

The apparatus consisted of a box carrying a vertical scale on the front. Settings of the pointer of this scale could be made by rotating a knob on the right-hand face of the box. Each of the 360 subjects made one setting; half of these were upward and half downward and equal numbers were made from each of nine positions equally spaced on the scale.

For settings made from points towards the middle of the scale about 90 per cent showed that subjects expected a clockwise rotation of the knob to move the pointer upwards and an anti-clockwise to move it downwards. This tendency was reduced, however, to about 76 per cent when the initial position of the pointer was near one or other end of the scale. It thus appears that in addition to the predominant expectation of clockwise for 'up' and anti-clockwise for 'down', there was a tendency to move the control clockwise when the pointer was towards the bottom of the scale and anti-clockwise when it was towards the top whatever the direction of pointer movement that was required.

Holding, D. H. (1957), Direction of motion relationships between controls and displays moving in different planes. *J. appl. Psychol.*, **41,** 93–97.

An experiment is reported, the object of which was to investigate the expected relationships between seven arrangements of a display pointer moving at right angles to the plane of rotation of a control knob.

Where the control was operated by the right hand there was an overall tendency to turn the knob clockwise, combined with a tendency to move it clockwise to produce movements of the pointer away from the knob and anti-clockwise to produce movements of the pointer towards the knob. There appeared thus to be a combination of a general tendency towards clockwise movement combined with the tendency appropriate to a helical or screw-like coupling between the knob and the pointer.

Arrangements in which the left hand was used gave rise to no significant tendencies but left-handed subjects gave significantly more anti-clockwise responses than right-handed.

On the whole it is not advisable to employ any of the combinations explored in this investigation unless movement is to be restricted to adjustment in one direction only relative to the control.

Siddall, G. J., Holding, D. H., and Draper, J. (1957), Errors of aim and extent in manual point to point movement. *J. Occup. Psychol.*, **31,** 185–195.

The object of this experiment was to compare the magnitude of errors of aim with errors of extent in simple discrete movements carried out at a high rate and in different directions relative to the position of the subject. Forty-eight subjects were required to draw four lines in succession from a starting point to a target as fast as possible. A lower limit to the speed was set by demonstration and brief training. Four directions of movement were compared: left to right, right to left, outwards from the front of the body and inwards towards the body. Errors in extent and deviations to left and right of the target were recorded as was the duration per four movements.

It was found that :

1. Errors of extent were significantly greater than errors of aim.

2. Constant errors of extent were overshoots and constant errors of aim were deviations to the right of the target.

3. There were no significant differences in accuracy between the four directions of movement.

4. Duration of left to right movements was significantly less than movements in the other three directions.

5. Speed and accuracy were negatively correlated.

Holding, D. H. (1957), Verbal training for motor skill. *Durham Research Review*, **2,** 175–180.

It is not clear how far learning with words assists later motor performance : despite the sanction of common practice, the experimental support for verbal pre-training is meagre. There are a number of experimental and semantic ways in which the stimuli and responses of the verbal tasks may be related to the elements of the motor task, and an analysis of these is the basis for discussing the existing evidence. The most common theoretical model is that of ' stimulus predifferentiation ', which is taken to be facilitating ; however, it is shown that this kind of training may often be expected to hinder rather than assist performance since it gives the subject competing verbal and motor responses to some stimuli.

A survey of experiments in this field shows that this prediction is borne out in several cases. It is further shown that verbal training is commonly inferior to other forms of pre-training, although the type of motor task investigated has been very restricted, and a number of possible combinations between verbal training and motor tasks have not been examined at all.

Weldon, R. J., and Petersen, G. M. (1957), Effect of design on accuracy and speed of operating dials. *J. appl. Psychol.*, **41,** 153–157.

Three types of multiturn dials, on which a range of numbers from 0 to 999 can be set, were tested for accuracy and speed in setting and checking. The results of 6200 settings and 6200 checkings made by 124 college students are reported. A commercial counter-type dial was found to be significantly more accurate than a commercial scale-type dial. Speed of operation was also significantly faster on the counter-type dial. An experimental-type dial of a modified scale design was found to be almost as accurate as the counter dial, although slower to operate. Because of its simplicity it should have a useful place in dial-setting equipment provided its design is improved to bring its scale and numerals up to recommended size.

A SYMPOSIUM ON ENGINEERING PSYCHOLOGY, under the chairmanship of PROFESSOR GELDARD, was held at the 1957 Annual Conference of the British Psychological Society. Four of the papers presented have been published in *Occupational Psychology*, **31**, 4, *October* 1957 :

Pp. 218–224. HARRY KAY, '*Information Theory in the Understanding of Skills*'. Information theory is discussed as providing a measure of input as well as output in skilled performance. The human operator is regarded as a limited capacity channel transmitting signals coming both from an external display and from internal sources. The operator can reduce the difficulty of a task by learning the significance of some signals and the redundancy of others.

Pp. 225–233. C. H. BAKER, '*The Objective Study of Judgement and Decision-Taking*'. The distinction is made between decision-making and decision-taking. The former refers to prediction built up on the basis of past events within the experimental situation. The latter involves the taking of action based on the evidence actually present. A summary is given of American and British work which stresses the need to reduce unessential information for the attainment of efficiency.

Pp. 234–242. W. T. SINGLETON and R. SIMISTER, '*The Design and Layout of Machinery for Industrial Operatives*'. Two examples of the application of human engineering principles to machine design and layout in shoe factories are described. The provision of extra foot controls on a sewing-machine so that the needle could be stopped in an 'up' position without requiring the operator to take his right hand away from his work, has resulted in better control of the machine, improved productivity by more than 25%, and made the job easier. The second example is the replanning of the layout of closing-rooms by determining the load at each station and the density of traffic between the various stations. This has resulted in an increase in piece-work earnings for operatives, mainly due to the improved method of supply of work and a general shift in work tempo.

Pp. 243–247. W. DOUGLAS SEYMOUR, '*Transfer of Training in Engineering Skills*'. Experiments on transfer of training in industrial skills have lacked adequate definition of the skills involved in the two situations between which transfer may occur. Experiments have recently been carried out in the Department of Engineering Production at Birmingham University, on the changes of performance that occur with improvements in skill on an electrical assembly task involving reaching, grasping, moving and positioning movements. Improvement was shown in the reduction of the number of long therblig times, rather than in a steady reduction of all therblig times.

It is suggested that the subject must have some knowledge of the results of his actions coming from kinaesthetic information—some recognition of certain attempts being more successful than others, which enables him to select these particular responses. His criterion of achievement and selection may be based not on time taken but on amount of muscular effort.

Part of R. Conrad's contribution to this Symposium will be published shortly in *Journal of Electronic Engineers*. An experiment on the effects of changes of traffic levels on the work of operators at a cordless auto-manual telephone exchange is described.

Part has already appeared in Conrad, R., and Hille, Barbara A. 'Memory for long Telephone Numbers', *Post Office Telecommunications Journal*, 1957, **10**, 37–39. The introduction of subscriber trunk dialling is likely to pose a memory problem of considerable difficulty, resulting in increased incidence of wrong numbers. Several experiments on the effects of various presentations of numbers on memory span are described.

C. B. Gibb's paper will be published in '*Études sur la Cybernétique et l'Economie*, 1958, **2**. (Paris : L'Institut de Science Economique Appliquée.) A brief account is given of biological findings which support the belief that there are essential similarities between the control characteristics of human movement, and those of analogous devices developed by servo engineers. The bearing of these analogies upon the study of transfer of skill is discussed.

ERGONOMICS RESEARCH SOCIETY

THE PROBLEMS OF TRAINING

The next annual symposium of the Society will be on the above topic, and will be held at the University of Bristol from April 13–16 inclusive. Training is a matter of much concern both in practice and in theory, and to both physiologists and psychologists: the papers to be presented cover all these aspects. The morning of Monday will be given up to psychological papers from various academic and practical points of view; the afternoon will include papers on physiological work and on border-line questions of environmental conditions. On Tuesday morning there will be further physiological papers, and in the afternoon a symposium on a particular method of industrial training followed by papers concerned with naval applications and with bibliography. It is hoped to arrange a symposium on training of older persons on the Wednesday morning.

Provisional Programme

Sunday Evening :	Opening Address—P. H. St. J. Wilson, C.B., C.B.E., Under Secretary, Ministry of Labour and National Service.
Monday Morning :	Dr. I. J. Blain (N.I.I.P., London). "Practice and Knack." J. Annett (Institute of Experimental Psychology, Oxford). A paper comparing various forms of knowledge of results during learning. Brigadier F. I. de la P. Garforth (Engineering & Allied Employers' West of England Association, Bristol). "The Problem of Management Development in Industry." Dr. E. R. F. W. Crossman (Department of Psychology, Reading). A paper on results from industrial experiments.
Afternoon :	Professor A. Hemingway (Department of Physiology, Leeds). "Physiological bases of training." Professor E. A. Muller (Dortmund). "Maintenance and increase of muscular strength." Dr. A. Lundervold (Oslo). "Training: an experimental investigation." J. G. Fletcher, M.Sc. (M.R.C. Hampstead). "Adaptation in man to exhausting physical work." D. E. Broadbent (M.R.C., Cambridge). "Effects of noise early in training upon subsequent performance." Commander Dean Farnsworth (U.S.N.) "The Habitability Program for Submarines, Airships and Certain Other Long-Duration Task Units."
Tuesday Morning :	Dr. F. H. Bonjer (Leiden). Mr. G. T. Adamson (Department of Physical Education, Leeds). "Circuit training." Professor O. Graf (Dortmund). "The effect of fatigue on training." Dr. J. E. Cotes and Dr. F. Meade (M.R.C. Cardiff). "Factors influencing the reduction with training in the pulmonary ventilation during standard exercise." Dr. M. J. Karvonen (Helsinki). "Problems of training of the cardiovascular system."
Afternoon :	W. D. Seymour. W. T. Singleton (S.A.T.R.A., Kettering). W. E. Sutcliffe (Cotton Board Productivity Centre). "Symposium on industrial training." Dr. F. V. Taylor (U.S. Naval Research Laboratory, Washington). "Limitations of a Procrustean Approach to the Optimization of Man-Machine Systems." D. Wallis (Department of Senior Psychologist, Admiralty, London). "Training Problems in the Field of Perceptual Skills." Dr. Ezra Saul (Tufts College, Mass.). "Human Factors Documentation with Special Reference to Training."
Wednesday Morning :	Dr. J. V. G. A. Durnin (Glasgow). "The effects of different grades of short-term exercise on the physical fitness of some young men." F. Hill (Wool Employers' Council R.E.T. Dept., Bradford). A paper on industrial training. A. T. Welford (Department of Psychology, Cambridge).

[Full details of this meeting may be obtained from Mr. S. Griew, Department of Psychology, 22 Berkeley Square, Bristol, 8.]

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